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Daniel Walter Morehouse
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By PHILIP FOX

In the death of Daniel Walter Morehouse, President of Drake University, astronomy lost a devoted advocate, university education an able administrator, and the many who knew him an earnest and loyal friend.

He was born at Mankato, Minnesota, on 22 February 1876. His childhood and youth were spent in Grant County, South Dakota, where he received his early schooling and where at eighteen he taught in country school. In 1897 he entered Drake University at Des Moines, Iowa, transferring from Northwestern Christian College at Excelsior, Minnesota. From that date his life was intimately associated with Drake University, as student, graduating in 1900, as instructor, professor, dean, and president (since 1923) with only brief absences for study, carrying a heavy load of teaching and administrative duties. As an undergraduate he was active in student affairs. His powerful physique and determination placed him at center in the Drake football teams. His great strength made him even in later years incautious of overwork. I doubt if any American university of comparable size was conducted with proportionally less overhead expense. Even under the very difficult conditions confronting privately endowed institutions in recent years his schedule contained some teaching and some observing.

Under his initiative and persuasiveness the Drake University-Municipal Observatory was erected. He directed its activities, formulated its program, and participated in the observing and the public lecture series. This institution has been well described by Dr. Morehouse in *A.S.P.* **33**, 327; *P. A.* **29**, 223-4; *P. A.* **30**, 61-65; *Jour. R. A.S.C.* **16**, 169-174. I believe he was never happier than when in this observatory, though not infrequently these happy hours were stolen from the few he should have allowed himself for rest.

His publications are for the most part on cometary and planetary observations with at least four eclipse expeditions thrown in for good measure. These expeditions were to Matheson, Colorado; Catalina Island, California; Island Pond, Vermont; and Giggleswick, England. The account of the first of these, 8 June 1918, appeared in POPULAR ASTRONOMY **26**, 551-7.

Among other publications may be cited:

Orbit of Asteroid 1909 JA., *P. A.* **19**, 452, with Seth B. Nicholson and Miss Alma M. Stotts.

Position of Lutetia (21), *P. A.* **19**, 534.
Longitude of Drake University-Municipal Observatory by Wireless, *P. A.* **23**, 65-74.
Total Solar Eclipse 8 June 1918 at Matheson, Colorado, *P. A.* **26**, 551.
Observations 6th, 7th, 8th Satellites of Jupiter, with W. F. Meyer, *L.O.B.*, 217.
Photographs of Halley's Comet, *P. A.* **18**, 370, 426.
Observations of Morehouse Comet, *P. A.* **17**, 122; *A.N.* **180**, 133.
Exposures on Comet 1919 *b* (METCALF) = 1847 V (BRORSEN), *P. A.* **27**, 627.
Drawings of Mars and Jupiter at Opposition of 1922, *P. A.* **30**, 461-4.
Variable Star R.A. $5^h\ 9^m7$ Decl. 34° 12′, *H.C.O. Bull.* 786.
Leonids *P. A.* **15**, 644.

During 1902 Morehouse was registered in the graduate school of the University of Chicago. In 1911-12 he continued his graduate studies and served as instructor in the University of California. In 1914 he received from that Institution the degree of Ph.D., the thesis being: The Orbit of the 7th Satellite of Jupiter. In *A.S.P.* **26**, 214, Professor Leuschner comments on this work stating that the solution was: First, To test the advantages of certain closed expressions; second, To test the accuracy of certain directions for taking full account of aberration; and third, To provide a set of osculating elements as basis of any more rigid satellite theory.

The name Morehouse first came into general prominence through the discovery of the remarkable comet which bears his name. I recall the circumstances of the discovery very distinctly. During the summer of 1908 Morehouse was at the Yerkes Observatory studying and participating in the observing program. Few visiting astronomers were privileged to use the Bruce Photographic Telescope. This instrument, really two photographic telescopes on a single mounting, presented by Miss Catherine Bruce of New York to Professor E. E. Barnard and by him to the Yerkes Observatory, was nevertheless regarded by Barnard as in his special custody, and very few so won his confidence that they were accorded the privilege of using it. At the moment there comes the recollection of only S. A. Mitchell, Wilbur Cogshall, and D. W. Morehouse, who were so privileged. Not only was the instrument at Professor Barnard's personal disposition but, in using it, the Milky Way might not be trespassed on by others while the preparation of his great atlas was under way. On the evening of 1 September 1908 Morehouse had been assigned a region along the fringe of the Milky Way. Professor Barnard was one of the most generous of men, generous of his time, his personal interest, his material support. In recognition of the intensity of his concentration on his problems it is easy to overlook or forgive his few foibles. In this case the result was that the photographs registered a superb comet.

In mid-morning on 2 September 1908, as I came down from the 40-inch dome where I had been working with the spectroheliograph, I met

Morehouse as he came up from his dark room. There was excitement in his manner and voice so much so that he scarcely whispered as he spoke: "Fox, I think I've found a comet." When I asked him if it appeared on both plates he rushed down to the dark room and in a moment returned to report the confirmation. It may be added that two nights later, 3 September, Borrelly independently discovered this comet.

Every comet has its peculiar characteristics but the Morehouse comet in behavior proved to be the mose bizarre, most whimsical, most unpredictable of any heavenly vagrant ever discovered. Its shape changing abruptly from night to night, or even hour to hour, made it of deepest interest. As Barnard wrote (*P. A.* **16**, 596) "Transformations were so great and rapid that on 30 September there was almost no resemblance between the comet in the first picture and the last one of that night, an interval of less than four hours." Its behavior upset some of the rather smug theories formulated to account for the more conventional changes of form. For this discovery Dr. Morehouse received from the Astronomical Society of the Pacific the customary award of the Donohoe Comet Medal (*A.S.P.* **20**, 286). With this comet the name "Morehouse" will go flaming through space for ages.

Ample testimony to the inspiring character of his teaching is provided by the records of such students as W. F. Meyer and Seth B. Nicholson.

Morehouse touched far more people than most astronomers, not only because Comet Morehouse was on every tongue but because he lectured widely and was influential in educational and church conferences. He spoke always impressively and reverently when lecturing on astronomy. He never failed to win the respect of his audience and attention to his discussion. In the Adler Planetarium, where incidentally he was often a guest lecturer, no astronomer was inquired after more frequently.

One of Dr. Morehouse's late addresses was presented as retiring Vice-president, Chairman of Section D of the American Association for the Advancement of Science, on "Astronomy's Contribution to the Stream of Human Thought" (Science Vol. 75, 8 January 1932, p. 27). This fine address is representative of the many he gave the country over.

His home life shared by his wife, Myrtle Slayton Morehouse, and his three children, Charles, Vega, and Frances, was delightful. A home of wise counsel and well-merited mutual respect, good reading, good music, good cheer. All three children married during recent years and established their own homes. Grief again struck the family in the death of Vega's husband, Edward C. Lytton, on 12 February 1941. The family is cheered by the grand children, young Daniel, Charles' son, and Frances' (Mrs. Glomset) daughter. These two inherit a very noble strain.

During the many Commencement exercises at which Dr. Morehouse presided at Drake University he had the privilege of presenting to the trustees many candidates for honorary degrees. In all such cases he summarized their contributions with graceful and apt characterizations.

If now one were to undertake to present in a few words a characterization of Daniel Walter Morehouse he would note the deep humility and unfailing courtesy, "the manner of a Virginia gentleman with the democracy of an Iowan," a profound genuineness and sincerity, a spirit touched with awe, seeing acquisitions of science as triumphs of the irrepressible human spirit comparable to religious faith, a willingness to work indefatigably, serious but not taking himself too seriously, a rather surprising vein of humor, a great love for his family and friends, spiritual aspirations to match his great stature, with human sympathy as broad as his great shoulders, a valiant crusader for understanding and tolerance.

14 MAY 1941, 316 FEDERAL BUILDING, MOBILE, ALABAMA.

The Physical Condition of Novae at Minimum

By DEAN B. McLAUGHLIN

INTRODUCTION

Several authors have calculated the radii of novae before outburst, but all such computations are necessarily based on assumed temperatures. Sometimes the temperature was taken as identical with that at maximum light, even for novae which exhibited a conspicuous change of spectrum as maximum was approached. In other cases the temperature was assumed to be that of a main sequence star having the same absolute magnitude as the pre-nova star. The radii and other characteristics thus deduced have led to some confusion, and some of the published statements have been taken altogether too seriously by others who have quoted them. The most recent example of this is found in a recent popular book[1] where it is stated, as if it were an established fact of observation, that Nova Herculis had a spectrum of approximately solar type before outburst. Actually there is not a shred of evidence to support such a statement.

Little harm would be done if authors would consider a variety of hypotheses which could cover a large range of conceivable conditions. It would be especially worth while to work out the consequences of different hypotheses, with a view to establishing observational tests which would distinguish the correct one. This seems not to have been done. In particular, one possibility has been almost completely ignored, namely, that the pre-nova star may differ only negligibly from the post-nova object. That this at least deserves consideration is suggested by the identity of luminosity of the star before and after the outburst.

In view of the confused situation it seems desirable, at the risk of becoming tedious, to discuss the whole question as thoroughly as limitations of space will permit.

Nova Aquilae 1918, Before Outburst

The only existing *direct* observational datum relating to the physical condition of a pre-nova star is a faint record of the spectrum of Nova Aquilae 1918, if we omit recurrent novae from consideration. The best of several faint spectra is described by Miss Cannon[2] as follows (the italics are mine):

> "The spectrum appears to be nearly continuous, perhaps due to faintness. Several narrow dark lines are, however, *barely seen*, which *appear* to belong to the hydrogen series. In the distribution of light, the spectrum resembles those of classes *B and A*. While the spectrum *cannot be classified*, it is safe to say that it was not of class G or K, but was *near* class A."

The angular rate of expansion of the nebular envelope about Nova Aquilae, in conjunction with the radial velocity of the outward-rushing gases, indicates a parallax[3] of 0".0028 which, with the apparent magnitude at minimum, 10.8, gives an absolute magnitude of + 3.0.

On these facts is based the oft-quoted statement that Nova Aquilae was a normal main sequence star of class A before the outburst. Examination of any of the published spectrum-luminosity diagrams will show that an average A0 star is fully two magnitudes brighter, and that Nova Aquilae falls near the limit of scatter of the points.[4] In interpreting this, we must remember that much of the scatter is due to accidental errors of the trigonometric parallaxes, rather than to a real spread of the luminosities of the stars. On the other hand, the "nebular expansion parallax" has accuracy of a higher order. If Nova Aquilae was truly of class A, it was not a normal main sequence star, but a "subdwarf". If it was of class B, which is allowable, according to Miss Cannon, it was even farther removed from the normal average luminosity of the class. A significant revision of the luminosity does not appear probable; for some reasons impossible to detail here, a slight change towards *lower* luminosity is suggested.

The Luminosities of Novae

At a later date the writer hopes to discuss in detail the determination of luminosities of novae. For our present purpose, the general results will suffice. A number of different methods now converge upon —7 as an acceptable value for the average absolute magnitude (photographic) of novae at maximum light. The novae in the Andromeda spiral appeared to be less luminous, according to Hubble,[5] who derived the value —5.7. But a re-reduction with the use of an improved average light curve for extrapolating back to the unobserved maxima has since removed the discrepancy.[6] Other determinations for novae in the galaxy have also given lower values, but they were carried out before the general absorption of light in the galactic system was recognized, and correction for such space absorption would bring them into accord with the value —7.

We shall not be committing any serious error by assuming, for pur-

poses of calculation, an average absolute magnitude of —7.0 at maximum for an average typical nova. The average range from minimum to maximum is close to eleven magnitudes.[7] We therefore adopt + 4.0 for the mean absolute magnitude at minimum. The apparent magnitudes at minimum represent a rather heterogeneous mixture of visual and photographic determinations, since some are photographic observtions before or after maximum and others are visual magnitudes determined afterwards. For definiteness, we shall consider this as the visual magnitude, remembering that the photographic magnitude, for a star of very early spectral class, could be about 0.5 magnitude brighter.

Enough examples are now known to justify the assertion that, photographically at least, novae are very nearly of the same luminosity before and after the outbreak. No typical nova has definitely come to rest at a magnitude conspicuously brighter or fainter than that of the prenova star.[8] Such differences as have been noted refer to objects for which the observations are scanty, and could easily be non-representative if the stars had a small range of variation before or after the outburst.[9]

Spectra and Temperatures of Old Novae

The nature of the spectra of novae after the end of the decline of light is now well established. Humason[10] found that, without exception, sixteen former novae, observed from 3 to 88 years after outburst, showed continuous spectra extending well into the violet, indicating temperatures comparable to those of early B- and O-type stars. In addition, many of these had more or less conspicuous emission lines of hydrogen and ionized helium, and occasionally neutral helium. Emission was present at 4650 CIII in some of them. No absorption lines were recorded.[11]

No determinations of either color temperature or photo-electric temperature are available for ex-novae. However, we can arrive at a rough value from the character of the spectra. The violet extension indicates temperatures surely above 30,000°K, but how much higher is not determinable from qualitative examination. The relative intensities of emission lines of hydrogen, ionized helium, and neutral helium, indicate temperatures about the lower limit of those of Wolf-Rayet stars. If the relation of band width to spectral sub-class, which appears to hold among Wolf-Rayet stars,[12] is valid also for ex-novae, then according to that criterion also, their temperatures must be at the lower limit for the class. Beals[13] gives photo-electric temperatures of such stars as 59,000°K (class WN8) to 70,000°K (class WC8). Since we are to be concerned with bolometric magnitudes, we should use *effective* temperatures, which are generally lower than either color or photo-electric temperatures. We shall therefore carry out most of our calculations with an assumed temperature of 50,000°K for the post-nova star. This is admittedly the most uncertain portion of our procedure.

Radii and Densities of Old Novae

For temperatures above 30,000°K the well-known approximate formula

$$\log R = 5900/T - 0.2\,M_v - 0.02 \qquad (1)$$

becomes increasingly inaccurate. We shall avoid these errors by transforming to bolometric magnitudes. Then, from the Stefan-Boltzmann law, we have

$$M_b = 10 \log [T_o/T\ (\text{star})] - 5 \log R + M_o \qquad (2)$$

where T_o and M_o, respectively, are the effective temperature and the bolometric absolute magnitude of the sun, and T (star) and M_b are respectively the effective temperature and bolometric absolute magnitude of the star. Using $T_o = 6{,}000°K$, $M_o = +4.8$, we obtain

$$\log R = 8.52 - 2 \log T\ (\text{star}) - 0.2\,M_b. \qquad (3)$$

Now, for a post-nova star of visual absolute magnitude +4.0 and various assumed temperatures given in the first column of Table 1, we obtain the data shown in the remaining columns. The correction to bolometric magnitude in the second column is from Pike's[14] table. The resulting bolometric absolute magnitude is given in the third column, and the radius, computed from equation (3) is in the fourth. The fifth column contains the "reduced bolometric magnitude," obtained by applying to the data of the third column the term 2 log [T (star)/5200]. With this reduced bolometric magnitude we enter Eddington's[15] table of the mass-luminosity relation to obtain a rough value of the probable mass of the star, which is given in the sixth column. The resulting density is tabulated in the seventh column.

Table 1

Theoretical Radii and Densities of Ex-novae, $M_v = +4.0$

Temperature	Bolo. Corr.	Bolometric Abs. Mag.	Radius	Reduced Assumed Bolo. Mag.	Mass	Density
30,000°K	—2.6	+1.4	0.20 ⊙	+2.9	1.5 ⊙	188 ⊙
40,000	—3.5	+0.5	0.17	2.3	2	410
50,000	—4.1	—0.1	0.14	1.9	2	730
75,000	—5.4	—1.4	0.11	0.9	3	2250
100,000	—6.4	—2.4	0.10	+0.2	3.5	3500

The calculations for 30,000°, 75,000°, and 100,000° are pretty surely outside the allowable range, but they are included to show the effect of such extreme assumptions. The writer regards 50,000° as close to the upper limit allowable, considering the spectral characteristics of old novae as compared with Wolf-Rayet stars.

Although the densities are high, they fall far short of the values for true white dwarfs, unless we adopt temperatures above 100,000° or assume improbably large masses. The bolometric luminosities are far above those of white dwarfs under any set of assumptions. The above calculations also allow slightly larger masses than most previous investigators have estimated. The common procedure has been to assume that the *visual* absolute magnitude of +4 indicates a mass about equal to

that of the sun. But the mass-luminosity relation refers to *bolometric* absolute magnitude, and the large bolometric correction compels us to assume larger masses.

We thus conclude that the post-nova stars are objects of high temperature, definitely too luminous and not sufficiently dense to be white dwarfs, with radii roughly 0.1 to 0.2 times the sun, and densities of order 1000⊙. The term "sub-dwarf" is applied to stars which lie a few magnitudes below the main sequence, and this term may well be extended to include the ex-novae at the high temperature end. Humason[16] reached conclusions similar to these, though he calculated somewhat lower densities. This resulted from comparison with a "normal O-type star," for which he assumed the absolute magnitude, mass, and density, and from lower assumed masses for the ex-novae. But the present results bear out his general and important conclusion that the old novae are not true white dwarfs.

Temperatures of Novae During Decline

Objections could be raised to the above conclusions on the ground that the assumed temperatures are much too low. It is well known that, during its decline through the nebular stage of its sequence of spectral changes, every nova shows emission bands due to highly ionized atoms, which would imply a very high temperature in the stellar nucleus. It is also well established that the color temperature increases as the light declines. Thus, both Nova Herculis and Nova Lacertae 1936 near maximum had color temperatures only a little above the solar value, but by the time they had declined four magnitudes or so, the temperatures indicated were of the order of 30,000°K.[17] In later stages photo-electric temperatures considerably higher were indicated. For Nova Lacertae, Beals[18] found temperatures of 60,000° to 75,000°K between July 2 and August 24, with rather definite indications of increase of temperature with the passage of time. But all these figures apply to the decline of light,—indeed to the *middle* of the decline,—and not to the conditions after the nova has come to minimum again. There is no justification for the assumption that, because the temperature showed an increase during the first several magnitudes of the decline, it will continue to increase all the way to minimum. It seems at least possible that the last subsidence of activity would be accompanied by a decline of temperature.

To illustrate how temperature changes might operate in the latter part of the decline of light, assume a star in the post-nova stage corresponding to the middle line of Table 1: temperature 50,000°, radius 0.14 ⊙, absolute magnitudes −0.1 bolometric and +4.0 visual. Now assume that in the later stages of the decline of light it had the same effective radius, but a higher temperature. We may then calculate the bolometric and visual magnitudes by use of equation (2) and Pike's table. The results are given in Table 2.

TABLE 2

Hypothetical luminosities of a nova during later decline

Temperature T	Bolometric Abs. Mag M_b	Bolo. Corr.	Visual Abs. Mag. M_v
120,000°K	—3.9	+6.7	+2.8
100,000	—3.1	6.4	3.3
80,000	—2.1	5.6	3.5
60,000	—0.9	4.6	3.7
50,000	—0.1	+4.1	+4.0

Evidently a difference of more than one visual magnitude could arise from a change of the temperature of the star from 120,000° to 50,000°K at the end of the decline of light, but we cannot call on a decrease of temperature to account for a greater loss of visual luminosity. Greater changes in the brightness of the star alone must involve changes of effective radius of the star.

The available spectrographic evidence indicates that the expanding nebulous shell contributes an important fraction of the total observed light of a nova from six to eight or nine magnitudes below maximum (in the typical average case, with range eleven magnitudes). But the nebular lines then weaken, and during the last two magnitudes of the decline the nebulous shell is too faint to give an appreciable fraction of the total luminosity. In this final stage of the decline the light curve refers essentially to the star itself, and not to the integrated light of the star and nebulosity. There is probably a single exception to this rule among recent novae: Nova Persei 1901 ejected an unusually brilliant nebula which undoubtedly caused the light curve of that nova to decline more slowly in its later stages than would be expected for a nova whose earlier development was so rapid.

There is some observational evidence for a decrease of temperature of the stellar nucleus near the end of the decline of light. During a recent visit to the Mount Wilson Observatory, the writer had the privilege of examining spectrograms of novae during the later stages. Such observations are available for Nova Lacertae 1910, Nova Geminorum 1912, Nova Aquilae 1918, and Nova Cygni 1920. Full details need not be presented here, but the evidence will be summarized.

A decrease of the temperature of such a hot star, giving a continuous spectrum with bright lines, may be expected to show up particularly in a fading of lines which require high excitation and strengthening of those of lower excitation. The line 4686 HeII is in the former class; the hydrogen lines are in the latter.

Nova Lacertae 1910 is non-committal; spectrograms taken in both 1913 and 1915 show Hβ practically equal to 4686. When next observed in 1936, the spectrum was continuous.

Nova Cygni showed 4686 becoming stronger relative to hydrogen between 1923 and 1927, but this probably represented fading of the hydrogen emission of the *nebula* during that time, since the forbidden

lines of OIII faded considerably during the same interval. In 1936 to 1938 there was possibly a slight weakening of 4686 relative to hydrogen. At this time the nebular emissions were absent, so the change undoubtedly refers to the stellar nucleus.

Nova Geminorum 1912, observed in February and May, 1914, showed marked fading of the forbidden lines, while 4686 was much stronger than Hβ. In 1915 to 1917 the forbidden lines of OIII were absent, and 4686 was still much stronger than hydrogen. In 1933, however, a spectrogram showed 4686 and a few hydrogen emissions all very nearly equal.

Nova Aquilae 1918 is the most extensively observed of these. In 1919 the 4686 emission band showed a central narrow undisplaced knot which clearly originated in the stellar nucleus, and not in the nebulous shell. No such knot appeared in the OIII or hydrogen bands. It remained strong for several years, but hydrogen emission knots of similar width gradually emerged during the years 1923 to 1925. The last observations, in 1938, show the hydrogen lines fully as strong as 4686. The emergence of hydrogen in 1923-25 coincides approximately with the last magnitude of the decline of light.

Nova Geminorum and Nova Aquilae thus clearly favor the hypothesis of a decrease of temperature of the star at or near the end of the decline. Nova Cygni is perhaps favorable; at least it gives no evidence to the contrary. Nova Lacertae 1910 may have remained constant, but the observations are insufficient. We may conclude that there is some support for the hypothesis that the highest temperature of a nova occurs, not at minimum light, but during the decline a couple of magnitudes above minimum.

Test of the Hypothesis of Collapse

We now consider some consequences of the hypothesis that a normal main sequence star of solar type may collapse, becoming a white dwarf (or a sub-dwarf, like the known ex-novae) and incidentally release enough gravitational potential energy to account for the outburst. There is no denying it would account for the amount of energy released; it is embarrassingly over-productive. Such a collapse is adequate to explain a supernova; it would release fully 10^5 times the energy of a common nova. Thus, Unsöld[19] calculated that a common nova liberates 6×10^{44} ergs, and Milne[20] found that the energy released by collapse would be about 10^{50} ergs.

We are concerned particularly with the effect on the observed luminosity of the star. According to Milne the post-nova luminosity should be the same as the pre-nova value. The star will have shrunk to smaller dimensions, but its temperature will have been raised just enough to leave its luminosity unaltered. But we must be careful to note that the theory refers to *bolometric* luminosity.

Consider a star identical in character with the the sun, of absolute

magnitude + 4.8, both visual and bolometric. Now suppose that it collapses and forms a post-nova star of the same bolometric luminosity with temperature 50,000°K. Then we must have

$$R_0^2 T_0^4 = R'^2 T'^4 \qquad (4)$$

where R_0 and T_0 are the radius and temperature before collapse and R' and T' refer to the collapsed star. Using $T_0 = 6{,}000°$, $T' = 50{,}000°$, we find

$$R' = 0.014 \odot, \text{ and the density, } \rho' = 343{,}000 \odot$$

The bolometric correction at $T = 50{,}000°K$ is 4.1 magnitudes, hence the *visual* absolute magnitude of the collapsed star will be

$$M'_v = +8.9.$$

That is, visually the star should be four magnitudes fainter after the nova episode than before. Photographically it would still be about three magnitudes fainter, if the bolometric magnitude were unchanged. This result is directly contradicted by observations. Put differently, this means that the observed equality of the pre-nova and post-nova photographic magnitude requires that the bolometric luminosity be three magnitudes brighter afterwards than before! No theory has been developed which requires such a situation. Indeed, one theorist made the error of pointing to the equality of photographic magnitudes as proof of the collapse theory, completely forgetting the bolometric correction!

For completeness, consider Nova Aquilae 1918, assuming a pre-nova temperature of 15,000°K, in keeping with its supposed B or A spectrum, and a post-nova temperature of 50,000°K. No assumption is necessary concerning the radius; we need only note the difference of the bolometric corrections for these two temperatures, which amounts to 3.3 magnitudes. That is, visually it should now be three magnitudes fainter than before, if the bolometric luminosity is unchanged, and the photographic difference should be only a few tenths of a magnitude less. The observed equality of photographic brightness then requires that it be now almost three magnitudes brighter bolometrically than before the outburst.

In view of the uncertainty expressed in Miss Cannon's description of the pre-nova spectrum, we would do better to conclude that the spectrum and temperature were very nearly or precisely the same before and after, and that no collapse has occurred at all. The most definite characteristic of the pre-nova spectrum was evidently its violet extent, which was fairly comparable to that of the known old novae. When ordinary glass prisms are used, the violet extent of a class O continuous spectrum is not appreciably different from that of one of class B, or even class A. There is therefore nothing in Miss Cannon's observation to contradict the hypothesis that *the pre-nova star was as hot as the post-nova object.*

Repeating Novae

We have just seen that the hypothesis of collapse with radical change of temperature leads to results which either conflict with observations or are self-contradictory. We consider one more body of relevant facts.

There are three very clear examples of repeating novae:

T Pyxidis, three outbursts, 1890, 1902, and 1920.
RS Ophiuchi, two outbursts, 1898 and 1933.
U Scorpii, three outbursts, 1863, 1906, and 1936.

A probable fourth is Nova Sagittarii 1919, which had a smaller (or perhaps incompletely observed) increase in 1901.

In general these repeating novae have smaller ranges of variation than typical novae. Nevertheless, the ranges are large (6 to 9 magnitudes), increases sudden, the general form of the light curves typically nova-like, and the spectra of the two that have been observed near maximum (T Pyxidis and RS Ophiuchi) are decidedly nova-like. If we did not know of their repeating character, but had observed their light curves and spectra only at their most recent and best observed maxima, we would not hesitate to call them ordinary novae. Although it is dangerous to generalize from two cases, on the other hand those two cases do not present phenomena which compel us to regard them as radically different from other novae.

RS Ophiuchi was observed at Mount Wilson in 1923, ten years before its most recent outburst. In 1936, three years after maximum, the spectrum was quite different, but one taken a year later strongly resembles the pre-nova spectrum. Both show bright lines of hydrogen and Fe II on a continuous spectrum. The line 4686 He II is not seen on the 1923 plate, but it is conspicuous in emission on the 1937 spectrogram.

T Pyxidis was not observed spectrographically before the 1920 outburst. A Mount Wilson spectrogram taken 14 years after that maximum is practically identical in appearance with the spectra of several other old novae. It shows a continuous spectrum with strong emission at 4686 He II and weak emission lines of hydrogen. It is interesting to speculate on the significance of this observation. The intervals between observed maxima are 12 and 18 years. If these are typical, and if we exclude the improbable assumption that the star will not continue to flare up at irregular intervals in the future, we must then believe that this post-nova observation refers equally well to the pre-nova stage of the next future outburst.

The very fact of the existence of repeating novae argues against the hypothesis that there is any drastic permanent change in the constitution of the star between the pre-nova and post-nova stages. It is hardly stretching a point even to note that the U Geminorum stars undergo mild nova-like outbursts at intervals of a few months, and that there is no indication of their "running down" or of a progressive change of the character of these stars over long intervals of time. Although their

spectra differ in a number of ways from those of novae, the resemblances are sufficiently marked to carry the conviction that the processes are essentially similar.

By analogy with the repeating novae, and without committing ourselves to the belief that typical novae repeat after intervals of many centuries, we can infer that the typical novae are physically the same before and after the outburst. Whatever it is that causes the expansion of the surface stratum of the star and its ejection in the form of an expanding nebula, the main body of the star is ultimately revealed inside and quite unchanged in its essential physical condition.

Novae, Planetary Nuclei, and Wolf-Rayet Stars

The nuclear stars of planetary nebulae and the Wolf-Rayet stars are often pointed out as related to the novae. Comparison of ex-novae with these objects is therefore of considerable interest. Data used for this comparison are taken from Beals'[21] recent paper. However the writer has computed radii independently, from equation (3).

In Table 3 the results are given for four objects, which were chosen to represent fairly well the extremes for the two classes. The first two entries refer to nuclei of planetary nebulae, the other two to Wolf-Rayet stars. The temperatures have been used as given by Beals, though they could have been reduced somewhat, in view of the usual difference between photo-electric and effective temperatures. The masses were assumed, as before, from the mass-luminosity relation. Perhaps these peculiar objects do not fit that law, but evidence on this point is very scanty.

Table 3

Theoretical radii and densities of nuclei of planetary nebulae and Wolf-Rayet stars

Object	Temperature	M_v	Bolo. Corr.	M_b	Radius	Reduced Bol. Mag.	Mass	Density
NGC 40	70,000°K	+0.9	—5.2	—4.3	0.48 ⊙	—2.0	8 ⊙	73 ⊙
NGC 7026	110,000	+2.4	—6.5	—4.1	0.18	—1.5	6	1040
HD 151932	72,000	—3.9	—5.3	—9.2	4.4	—6.9	100	1.2
HD 16523	110,000	—1.6	—6.5	—8.1	1.15	—5.5	50	33

The obvious result is that planetary nuclei are rather similar to the ex-novae (see Table 1); like the latter, they are evidently sub-dwarf stars, and not true white dwarfs. The Wolf-Rayet stars, on the other hand, are of much higher luminosity, larger radius, and lower density. Although the extreme case, HD 16523, approaches the densities of planetary nuclei and ex-novae, it lies outside the range of values of either.

The similarity of ex-novae and planetary nuclei immediately suggests the question: are the planetary nuclei ex-novae, and are the planetary nebulae the gaseous shells ejected by the outbursts of such novae?

On the affirmative side, we can point to the similarity of radii and densities, plus the resemblance of the planetary nebulae to the shells of

gas ejected by novae, and the observed doubling of the emission lines in the spectra of some planetaries, which indicates that they may be expanding. In addition, one object which is classified as a planetary, namely the Crab Nebula, has been identified, with considerable probability, with a nova recorded by Chinese observers in 1054 A.D.[22]

On the negative side, we note that ex-novae probably average two magnitudes less luminous than planetary nuclei and that their temperatures are somewhat lower. These, however, are probably not fatal objections. But the one planetary nebula which is identified with an ex-nova now shows very high velocities of expansion. Extremes measured by Mayall are —1340 and +1650 km/sec. Most planetaries, on the other hand, show little such effect. Several examples of conspicuous doubling of the lines at the centers are known, but the most extreme case recorded by Campbell and Moore,[23] NGC 2392, exhibits a difference of velocity of only 106 km/sec. The Crab Nebula is thus in a class by itself; it shows nova-like velocities of expansion, while the planetaries do not. Moreover, the planetaries have not shown visible changes in many decades,—they are at least semi-permanent celestial objects. The nebular shells around novae are extremely short-lived as a class; that of Nova Persei is the most persistent among recorded typical novae of the past century. We must therefore dismiss the picturesque hypothesis that planetary nebulae are the "wrecks of ancient novae" and admit that the resemblance is only superficial. They may have been formed from material ejected by the central stars, but the ejection was surely not of nova-like violence, and probably did not involve conspicuous variation of the central stars.

Limitation of Nova Activity

The evidence that has been presented indicates that the belief that any star in the sky can become a nova is untenable. On the contrary, nova activity must be limited to a small class of stars, the sub-dwarfs of very early type, the low-luminosity counterparts of the Wolf-Rayet stars. Barring actual collision (which is too improbable to account for the frequency of novae) the overwhelming majority of stars are immune. It follows, as a corollary, that the sun is in no danger of becoming a nova. Such a conclusion is hardly surprising; it is no more logical to expect any star chosen at random to become a nova than it is to expect it to become a Cepheid or long-period variable, and these classes of variables have a very limited range of physical characteristics. The apparently catastrophic nature of novae is the only justification for assuming them to be the evidence of accidents which can happen to any star. The existence of repeating novae and the similarity of novae to the U Geminorum stars nullify that argument.

The limitation of nova activity to a small class of stars, taken in conjunction with the frequency of their occurrence, indicates that either: (1) stars which can become novae are very abundant in space; (2) all

novae repeat in the course of time; (3) we are living at a very special time when all the potential novae are exploding.

It would lead us too far afield to discuss the evidence favoring these different suppositions. Considerations of the number of objects to be expected within range of observation is decidedly favorable to the hypothesis that all novae repeat. Otherwise, even if we are living in a favored time, space would have to be so densely populated with potential and ex-novae that they would have been recognized as a distinct class of objects in the spectral surveys that have been made.[24]

A recent theory of nova activity, proposed by Biermann,[25] is based upon just such a limitation of nova activity to sub-dwarfs of very early spectral class, which are considered to repeat at intervals of thousands of years. The pre-nova and post-nova objects are considered identical in all characteristics. However, the acceptance of the correctness of the conclusions reached in this paper does not necessarily compel a belief in the correctness of Biermann's theory.

Conclusion

It has been pointed out that ex-novae are sub-dwarfs of rather high temperature, with luminosities, radii, and densities intermediate between those of main sequence stars and those of true white dwarfs. In this respect they resemble nuclei of planetary nebulae, but such nebulae are probably not old novae.

The hypothesis that novae are main sequence stars before outburst has been shown to conflict with observation, as a result of the change of the bolometric correction which would accompany a change of temperature. The hypothesis of stellar collapse as the cause of novae is shown to lead to contradictions.

All these contradictions can be removed, and all observational evidence on both pre-nova and post-nova stars can be harmonized by adopting the *working hypothesis* that novae before outburst are practically identical in character with the objects observed after the nova episode is past. This definitely *relegates nova activity to a special class of stars*. It disposes of the contradictory belief that every star in the course of time must become a nova in order to account for the observed frequency of novae. It follows from this that all novae may repeat in intervals of many thousands of years.

The writer wishes to record here his indebtedness to Dr. Walter S. Adams and Mr. Milton Humason for placing at his disposal spectrograms of novae in their late stages.

Note

Since this paper was written, some of those with whom I have discussed the problem have objected that equation (4), $R_o^2T_o^4 = R'^2T'^4$, is a pure assumption, and may not be valid. This is granted, but it does not invalidate the arguments against the hypothesis of collapse. It still

remains true that *equal photographic* luminosity before and after collapse demands that the post-nova star be three magnitudes *brighter bolometrically* than the pre-nova object. If the original body fitted the mass-luminosity relation, then the collapsed star would be too bright for its mass. This is just opposite to the deviations of the white dwarfs, which are too faint for their masses. This contradiction is fully as difficult to reconcile as others which have been pointed out, and serves to strengthen the arguments which lead to the conclusion that no collapse is involved.

April 30, 1941.

References

[1] "The Birth and Death of the Sun," page 182.

[2] *Harv. Ann.* **81**, 179, 1920.

[3] Hubble and Duncan, *Aph. J.*, **66**, 59, 1927.

[4] See, for example, Nassau and McCuskey, *Mon. Not.*, **94**, 579, 1934. For class A0 they give a mean absolute magnitude $+0.8$, with a dispersion (corresponding to the probable error of a determination of ± 0.7.

[5] *Aph. J.*, **69**, 143, 1929.

[6] Hubble, *Publ. A. S. P.*, **50**, 108, 1938.

[7] McLaughlin, *Popular Astronomy*, **47**, 544, 1939.

[8] P Cygni is excluded from the typical novae.

[9] McLaughlin, *Popular Astronomy*, **47**, 490, 1939.

[10] *Aph. J.*, **88**, 228, 1938.

[11] The writer has examined these spectrograms and has been particularly impressed with the almost identical appearance of these spectra, aside from difference of intensity of the bright lines, which in no case are responsible for any considerable percentage of the total radiation.

[12] Beals, *Jour. R.A.S. Canada*, **34**, 171, 1940.

[13] *Ibid.*, 179.

[14] *Mon. Not.*, **89**, 539, 1929.

[15] "The Internal Constitution of the Stars," page 137.

[16] *Aph. J.*, **88**, 242, 1938.

[17] See, for example, Beileke and Hachenberg, *Zs. f. Aph.*, **10**, 366, 1935; Oehler, *Ibid.*, **12**, 281, 1936; Petrie, *Victoria Publ.*, **6**, 339, 1937. On the other hand, Popper (*Aph. J.*, **92**, 272, 1940) found no clear indication of change of color temperature, but his observations began two weeks after maximum.

[18] *Victoria Publ.*, **6**, 353, 1937.

[19] *Zs. f. Aph.*, **1**, 146, 1930.

[20] *Obs.*, **54**, 144, 1931.

[21] *Jour. R.A.S. Canada*, **34**, 180, 1940.

[22] Mayall, *Publ. A. S. P.*, **49**, 101, 1937.

[23] *Lick Publ.* **13**, 114, 1918.

[24] Of course, if the favored time interval were limited to, say one million years, we should not need to conclude that novae repeat. The author apologizes for so much as mentioning this absurd supposition.

[25] *Zs. f. Aph.*, **18**, 344, 1939.

The Observatory, University of Michigan, December, 1940.

George William Hill*

By FOREST RAY MOULTON

More than eighty years ago, for a period of four years from 1855 to 1859, a youth named George William Hill was a student in this institution. He did not come from a family of wealth or of high social position or of exceptional distinction in any way. His father and grandfather were artists descended from English stock and his mother sprang from Huguenot stock. From early boyhood he lived in the country by the Hudson River near West Nyack, New York.

In college young Hill did not become famous as an athlete nor was he prominent in college politics or social life. He was not a debater or a winner in intercollegiate oratorical contests. He did not have trouble with the college authorities or the local police. Probably in the eyes of his fellow students he led an uneventful and rather drab life.

When Hill left college he did not quickly make his mark in the world. He did not marry the daughter of a wealthy employer; in fact, he never married at all. He never held a prominent position, even in the field to which he devoted his life. He never received more than a very modest salary. He was rather retiring and without many intimate friends.

George William Hill entered this institution as unobtrusively as thousands of students have entered it during the 175 years since it was founded. Like thousands of other students he took its courses, passed its examinations, received a degree from it, and went out from its pleasant, sheltering halls and was lost in the busy life of the world. Yet of all the young men, the promising and the brilliant as well as the inconspicuous, who passed through Rutgers before his time, during his time, and since his time, he alone is the one in the honor of whose memory we meet today. We may well inquire what it was in his life, his personality, his achievements, his characteristics that has drawn us here. And we may inquire with equal reason what it is in us that makes us assemble at this place to honor his memory.

Many times during history men of obscure origin and modest achievements, as the world measures achievements, have founded religions that have endured for centuries after their deaths. Others have established philosophies or schools of thought. In all these cases the religions or philosophies have been clear formulations of things that were readily understandable because they were already sleeping in the hearts of men. But Hill founded no religion, philosophy, or fad. He led no crusade,

*This address was delivered at Rutgers University on the morning of February 11, 1941. In the afternoon of the same day Dr. Moulton gave a paper on Linear Differential Equations with Periodic Coefficients. These exercises were held in connection with the celebration of the 175th annivrsary of the founding of Rutgers University.

he aroused no mass emotions, he was the author of no slogans. He delivered no public addresses over the radio or otherwise. His words of wisdom were expressed in writing, and they never became a best seller, nor were they ever made the basis for a motion picture. In fact, they have been read and can be understood by only a few persons, perhaps by 500 of the 131,000,000 inhabitants of the United States. There is nothing mysterious or paradoxical about what he wrote, as there appears to be about such subjects as the fourth dimension or the theory of relativity. Yet we are here in honor of his achievements.

Many mystery stories have been invented. The mystery in this one illustrates the fact that truth is often stranger than fiction. If Sir Conan Doyle were describing what is happening here today, he would keep his readers in suspense for hours regarding the reasons for our actions. He would have them asking over and over again what it was in Hill and what it is in us that brings us here. But I am not a master of prolonging anxieties. Hence I will lead at once toward the explanation of the mystery by asking what we regard as the most important for us of all the things in which we are interested. I don't mean anything of temporary importance, however acute the need for it at the moment may appear to be. I mean something of such fundamental importance to us that in all our best hours, as when we are alone on the mountains, by the shore or under the stars, it stands out as the supreme basis for all our thinking, believing and acting, for our reason and our happiness. I should pause to give opportunity for each of you to formulate this abiding and satisfying principle, but the exigencies of time hurry us forward. I hope, however, that at your leisure you will reflect on this question for the purpose of determining whether you agree with what I am about to suggest, or whether for you there is something else more fundamental and lasting.

How difficult it is to decide offhand what we regard as important! If we were ill, we should want good health; if we were poor, we should desire riches. In a disordered world, we all long for security. If many persons were questioned, a thousand things would be suggested as most important. If the same persons were questioned at different times, it would be found that their opinions respecting what is most important had undergone changes. In posing this question for the purpose of discovering why we are assembled here, I have aroused doubts and filled your minds with uncertainties. If I had not done this you would be happier, at least for the moment. Uncertainties make us uncomfortable; we long for finality. Consequently, let us reflect on the problem of approaching certainty about the future. Perhaps in general terms that is what we regard as most important.

There would be no basis for predicting the future if the universe were a chaos. In a chaotic world everything would be uncertain—our health, or wealth, our happiness, our very existence. Since the antithesis of chaos is orderliness, we find that the common basis for the realization

of all our most ardent desires is an orderly universe and the ability to understand its order. Is the universe orderly? In answering, permit me to refrain from attempting to define precisely what we mean by orderly, and to ignore certain questions raised by recent theories in physics. With the latitude accorded me by these omissions, I unhesitatingly say that there is very convincing evidence that the universe is orderly. Scientists universally accept the conclusion—it is, indeed, the very foundation on which science rests. By their observations, experiments and reasoning scientists have established it with a degree of certainty higher than that of anything else we believe. To have reached the firm conclusion that the universe is orderly is the supreme achievement of science. It is dispelling the superstitions that have often darkened the history of mankind. It is destroying the corrupting hopes that by some luck or magic men may escape the consequences of their actions. The orderliness of the universe, so far as it is understood, is expressed in what we call the "laws of nature." This expression, however, is often misleading, for the word "law" in other connections implies compulsion or prohibition. The laws of nature are essentially descriptions of the way phenomena are related, with no necessary implication of causality. The statement that the universe is orderly means, therefore, that similar phenomena are always similarly related.

We may now inquire how the orderliness of the universe and our belief in it are related to our assembling here in honor of the memory of G. W. Hill. The answer is in part, that, in a special field, he made great contributions to the proof that the universe is orderly and that the human mind can comprehend it; and the answer is, in part, that perhaps without fully realizing it, we attach the highest importance to this great principle. Curiously it does not find its simplest and most certain illustrations in the things with which we are ordinarily concerned. A tree, the weather, the human body, our minds, society, all present enormous complexities. No wonder the ancients invented gods and goddesses on the mountains, in the forests, under the sea, to account for the things they could not otherwise explain. No wonder that the shelves of drug stores are laden with magical panaceas for countless real and imaginary human ailments. No wonder that there is general confidence that some political nostrum will cure the ills of society. In spite of what they may say, in these fields people on the whole do not believe in the orderliness of the universe.

But in the motions of the heavenly bodies orderliness is most easily established. In this field there are the fewest complicating factors, and in it order can be determined with the greatest degree of precision. There are thousands of observed peculiarities in the motions of the moon and the planets, all of which have been deduced from the law of gravitation. The agreements between theory and observations are not rough correspondences, like those between predictions of the weather and what actually happens. They are of extraordinary exactness, partly

for the reason that any error they might contain would increase with time like the error of a watch that is not exactly regulated. If you knew a man who predicted the precise rainfall at a place every day for five years, would you conclude that the weather is orderly and that the man understood its laws? I knew a man who made even more remarkable predictions concerning the motions of the moon and of Jupiter and Saturn, all of which were fulfilled, and his name was G. W. Hill.

We honor Hill because he made a remarkable contribution to the proof that at least in a certain field the universe is orderly, and because we realize, perhaps somewhat vaguely, that such a proof contributed to a conclusion of profound importance. He did his epoch-making work alone in his isolated home by the Hudson. He roamed serenely through intellectual regions which the mind of man had never hitherto explored. On everything he touched he left the marks of the master. Happy in his adventures and oblivious of the world's opinion, he made no dramatic announcements of his discoveries, but published them tardily with no flourish or hint of superiority. In fact, he published his greatest work privately, leaving out the details of its most difficult part because it would have cost $50 to include them. Fortunately the epoch-making character of this contribution to the Lunar Theory was recognized in Europe, and nine years later it was republished in *Acta Mathematica,* perhaps at the time the leading mathematical journal in the world.

There were certain characteristics of Hill's work which are of general interest. I have mentioned that his father and his grandfather were artists. He was a greater artist in a different way. It would be a serious error to think that mathematics is cold and austere. It has its harmonies, its symmetries, its proportions, its economies of expression, no less than do music, painting, sculpture, and poetry. It is generally, perhaps always, these aspects of their work that inspire mathematicians, as they inspire masters of the other fine arts. Certainly the best papers of Hill were exquisite works of art. I thrill at the memory of the way they impressed me when I first read them. I followed in awe and with delight the pathways he had trod, not haltingly and laboriously but with certainty and ease. In such happy hours I had the keenest appreciation of the serene dignity and the rare beauty of the superior human mind. Another characteristic of Hill's work was its completeness. He not only developed the logical essentials of the subjects he treated but he worked out the details of their numerical applications. In these respects he has had no superior in the field of celestial mechanics. He was a profound logician and an expert computer, two qualities that are quite distinct, though they are often confused. Hill once told me that in producing his tables of Jupiter and Saturn, between 1882 and 1892, he had carried out what he believed to be next to the most laborious algebraic and numerical calculation ever completed by one man. He gave first place to Delaunay's Theory of the Moon.

Lest some one might suspect that I have overstated Hill's ability and

fine qualities under the inspiration of this celebration, I shall present a few evidences of the high regard in which he was held by individuals and institutions in this country and in Europe. Many persons who were his friends have paid high tribute to his superior intellectual and personal qualities. Sir George Darwin, who spent more than ten years on the problem of three bodies, started from the work of Hill and freely admitted his indebtedness to it. Dr. R. S. Woodward, for many years president of the Carnegie Institution of Washington, wrote of him in the most appreciative terms.

By almost universal agreement Henri Poincaré, a Frenchman, had the most penetrating and brilliantly versatile mathematical mind of his generation and perhaps of the nineteenth century. His contributions to celestial mechanics, and especially to periodic orbits, were revolutionary. Concerning the work of Hill this great master said, in free translation:

"No part of celestial mechanics has been a stranger to him, but his own work, that which will make his name immortal, is the theory of the moon. It is in it that he has been not only a skillful artist, a curious investigator, but an inventor original and profound. . . . When (his methods) are extended to a vaster domain, it must not be forgotten that it is to Mr. Hill that we owe an instrument so precious."

Hill was a member of the National Academy of Sciences and the first Chairman of the Gould Fund to which I succeeded upon his death in 1914. He was honored by election as a foreign member of the Royal Society of London, as an associate of the Paris Academy and of the Belgian Academy, and of several other great societies. He was awarded the Gold Medal of the Royal Astronomical Society in 1887 when he was 49 years of age. He receiver later the Schubert prize from the Petrograd Academy, the Damoiseau prize from the Paris Academy, and, in 1909, the most distinguished scientific honor bestowed in the British Empire, namely, the Copley Medal of the Royal Society of London. Columbia University, Princeton University, his alma mater, Rutgers University, conferred upon him the honorary degree of LL.D., and Cambrige University, England, awarded him the honoray degree of Sc.D. These are formal evidences of the high value placed by competent judges on demonstrations that the human mind is capable of discovering and understanding important aspects of the universal order of which we are a part. Through such abilities and understandings we can reconstruct the past and look into the future, as has often and conspicuously been done in astronomy, for example, in predicting eclipses. It is an inspiration to know that human being have such powers as Hill demonstrated so brilliantly.

In spite of his great ability and the many honors he received, Hill was the most modest and retiring of men. His modesty and his absolute intellectual integrity are illustrated by one of his actions. In response to an invitation from Columbia University he offered lectures upon celestial mechanics. Since his lectures were not well attended, he soon

tendered his resignation. Thereupon he was invited to write them out for the use of future astronomers. Hill did this, but after the lapse of a year or two he returned to the university the entire sum paid to him. The real reason he did not retain the money was that he felt he had not given value received for it. To close the matter he stated that he did not want the money and that the care of it would be an annoyance to him. He did not need many of the things money can purchase. In addition to scientific work, more precious to him were the opportunities for freely exploring streams and forests and mountains. He sought out the haunts of the fragrant arbutus and trod the leafy hillsides covered with laurel blossoms. He knew the wildflowers and the trees of the Hudson and of the hills and ravines for a radius of twenty miles around Washington. He made several walking trips through the mountains of Virginia, West Virginia, and North Carolina, and two trips deep into the wilds of Canada. He followed established roads when they served his purpose, but often he struck out through the pathless woods to new beauties and heights, as he did in his scientific work.

We can rarely, perhaps never, explain the abilities of such a man as Hill. There was, however, one fortunate circumstance in his education that it is especially appropriate to mention in this place. He came under the influence of a remarkable man on the faculty, Dr. Theodore Strong, professor of mathematics. According to Hill, Dr. Strong was interested only in the classical treatises in mathematics extending down to the time of Poisson (1840) in the first half of the nineteenth century. Partly under the influence of Dr. Strong and doubtless partly because of his own ability and taste, Hill read while still an undergraduate more than 80 years ago such formidable works as Lacroix's Differential and Integral Calculus (if you will permit me to translate the titles), Poisson's Treatise on Mechanics, de Pontécoulant's System of the World, Lagrange's Analytical Mechanics, Laplace's Celestial Mechanics, and Legendre's Elliptic Functions. It is extremely rarely that an undergraduate college student of the present day reads corresponding books in any branch of mathematics. Hill not only read these great works but he understood them, as is proved in many of his writings. In fact, in the seventies he had arrived at a level of mathematical rigor that was not attained by any other astronomer, except Poincaré, until the early years of this century.

Although the pressures of life occupy most of our attention, it is advantageous from time to time to turn aside from them and to look back over the path we have traversed. This is what we are doing today. It is advantageous to do this because of the encouragements we get from past achievements and the warnings we get from past failures. Happily I have been assigned a subject that is not only pleasant but inspiring. Everything connected with the life and work of George William Hill increases our confidence that there is goodness in human beings and our respect for the human intellect. He has given us new and convincing

assurance that the universe is orderly and that it is not wholly beyond our comprehension. For all he contributed to this conclusion and for his example as a wholly upright man we hold him in grateful remembrance.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,
WASHINGTON, D. C.

Interesting Variable Stars*

By **CECILIA PAYNE GAPOSCHKIN and SERGEI GAPOSCHKIN**

S.G.—It is rather amusing to think that fifty years ago this discussion could not have been held, even if the radio had existed.

C.P.G.—Why do you think it could not have been held?

S.G.—Because only a few dozen variable stars were known, and even they had not been much studied or thoroughly understood.

C.P.G.—You are perfectly right. And what is more, five hundred years ago it would have been quite impossible, not only because variable stars were unknown, but also because nobody believed in the possibility of their existence. Aristotle had said that the crystalline sphere of stars was fixed and immovable, so that it was unthinkable for a star to vary in brightness.

S.G.—And yet now we know about twenty thousand variable stars.

C.P.G.—All discovered in the last fifty years.

S.G.—And fifty years hence we may expect that this discussion will also be impossible, because the material will probably increase to such proportions that a general discussion at one sitting could not be made.

C.P.G.—Now we have twenty thousand variable stars to choose from. What are you going to select as most interesting?

S.G.—It is the individuals that interest me. In a group of plants, or of animals, or of people, surely it is the personal peculiarities that are interesting.

C.P.G.—I am not sure that you can give a true idea about a group or a race by picking out an abnormal example from it.

S.G.—Neither am I. But that is not what I mean when I say that I am interested in personal peculiarities. My point is that if we study one variable star closely, if we dissect it, figuratively speaking, we shall be able to penetrate the nature of variable stars as a whole, and even of the stars in general.

C.P.G.—I have heard variable stars described as the pathological members of the stellar family. The last remark that you made does not sound as though you regard them in that light.

*One of the series of Harvard Radio Talks now being given. This one was given from station WRUL on February 22, 1941. For other talks in this series, see POPULAR ASTRONOMY for April, 1941, p. 191, and May, 1941, p. 236.

S.G.—Most certainly I do not. Variable stars are not to be thought of as abnormal stars. Probably most of them are constructed just like other stars. They simply happen to be placed in a situation in which they can be unusually active. We do not hesitate to apply to all stars the conclusions that we draw from the behavior of variable stars.

C.P.G.—Then the extremes of behavior shown by variable stars must have an especial interest. The variable star that varies the most rapidly must be of the first importance. I am thinking of the star called CY Aquarii, in the constellation of the "Water-carrier," which is rather larger than the sun, and which is pulsating regularly once in every 87 minutes and 53 seconds.

S.G.—When one tries to picture it, the thing is almost incredible. Imagine if the sun were swelling up by fifty per cent of its size, regularly every hour and a half!

C.P.G.—And it has been going on, I suppose, for centuries, if not for millennia.

S.G.—Yes, the star CY Aquarii is a good example of how rapidly a star can pulsate. But it is only one of the extremes. How many people know, I wonder, that the Pole star is pulsating rhythmically once in every four days.

C.P.G.—I have always thought that Shakespeare was singularly unfortunate when he put into Julius Caesar's mouth the famous words: "I am constant as the Northern Star." The northern star is about the most inconstant star known. Not only does it vary in brightness. It is also moving in a small orbit round an invisible companion. And besides that, the precession of the equinoxes displaces it continuously in the sky, so that it will not even be the Pole star very long, astronomically speaking.

S.G.—We ought to mention, too, that some stars take a week to pulsate, or a month, or a year. For example there is the star S Aurigae, in the constellation Auriga, "The Charioteer," that pulsates with a period of 578 days—about ten thousand times the length of the period of CY Aquarii, the first star that we mentioned.

C.P.G.—One of the most exciting phases of modern astronomy, I think, is the way in which we are beginning to understand what is happening to these pulsating stars, and why some of them are beating slowly, and some very fast. I have heard them likened to vibrating organ pipes. The slow ones are sounding very low notes. The quick ones are giving out higher notes. Some of the very fastest of all are behaving like pipes that have been overblown, and giving out notes higher than the fundamental. They are examples of the principle of the penny whistle on a cosmic scale.

S.G.—That gives a modern turn to the ancient concept of the Music of the Spheres. And because it is now possible to understand the extremes of pulsation—88 minutes and 600 days—we can also hope to understand all the intermediate cases. Now we can see the Great Se-

quence, not as a series of abnormal and diseased stars, but as a group of active individuals, whose behavior is intimately connected with their sizes, densities, and weights.

C.P.G.—I quite agree that the pulsating variable stars are very interesting. But we ought not to give the impression that they are the only kind. Why not mention the class of variable stars that are known as the New Stars?

S.G.—I am sure that most of our listeners must remember the bright new star that appeared a few years ago—why, it is already six years; time is ticking away indeed!—just about at this time of year.

C.P.G.—You must mean the famous Nova that appeared in the constellation Hercules. That was one of the most interesting variable stars ever discovered. It was so bright that we were able to study all sorts of phenomena in detail. First we saw it brighten by a hundred and forty thousand times. Then we studied its spectrum and found that it was swelling up—I ought really to say exploding. Then the explosion became directly visible. Two immense globes of gas were seen to fly out from the star in opposite directions and go sailing off into space. They can still be seen for that matter, but now they have settled down into a sort of luminous haze that is expanding on all sides.

S.G.—And about 18 months later a second bright nova appeared in the constellation of "The Lizard." Of course both outbursts really took place a good many centuries ago. Their light has taken all this time to reach the earth. And the two stars did not really explode 18 months apart. Actually, Nova Lacertae exploded a thousand years before Nova Herculis, but the news only arrived at the earth 18 months later.

C.P.G.—When the name "New Stars" was given to these objects that appear so suddenly, and then fade away after blazing for a few days or weeks, it was supposed that a new star had actually been created. That suggestion was startling enough. But I think that our modern picture of a star that suddenly "swells up and bursts" is even more fascinating.

Perhaps the most important of all the New stars was the one that appeared in 1572. We know now that a new star had not been created. But we can see that a new science was created the day that star was first observed. For the man who saw it was inspired to build the first modern observatory, and to lay the foundations of observational astronomy.

S.G.—Of course these novae are classical cases. Let us also recall those queer variables like U Geminorum, which resemble novae in many ways. They increase suddenly in brightness, and their colors and temperatures are more or less similar to those of novae. Some people have even called them "Dwarf novae." The principal difference seems to be that the U Geminorum stars explode less violently than novae, and that they do it more frequently, every few weeks or months; whereas only three novae have had more than one outburst, at intervals of many

years. It seems as though the U Geminorum stars are subject to continual gentle sneezing, whereas the true novae suffer from rare but violent sternutations. This analogy illustrates the point that the outbursts of novae, though conspicuous and violent, are not very fundamental, and probably leave the star comparatively unchanged in the long run, just as a sneeze is only a passing cataclysm.

C.P.G.—I should like to contrast the U Geminorum stars with the supernovae. If the former are at the foot of the nova class, the latter are at the head of it. These gigantic novae are enormous, bloated spendthrifts. They pour out as much energy in a year as the sun does in ten million years. In contrast to them, the U Geminorum stars are niggardly; 270 million of them would be equivalent to one supernova.

S.G.—While we are on the subject of interesting individuals I should like to mention the eclipsing stars. I might remind our listeners (I hope someone is still listening) that the eclipsing stars are double stars. The two components of the pair revolve around one another in an orbit and eclipse each other periodically. These eclipsing stars are very important among the variable stars.

C.P.G.—Let us plunge at once into the middle of the subject and mention a beautiful example—the variable star W Ursae Majoris, situated in the "Big Dipper." The components of this variable star are so similar that they may be considered as twins. If they were at the same distance as the sun, we should see what looked like two suns, revolving around one another every eight hours. They are very close together, so that their mutual gravitation pulls them out of their spherical shape. They would look rather like two eggs with their small ends almost in contact. Every four hours one of them comes between us and the other one, and we see a dimming of the light of the system.

S.G.—An even more interesting system is that of Castor, one of the bright stars in the constellation Gemini, the "Heavenly Twins." When the constellations were first named, there were no telescopes and only the naked-eye stars were known. Two bright stars were called Castor and Pollux, the Heavenly Twins, and gave the name to the constellation. But when the telescope and spectroscope were turned on the Heavenly Twins it was found that the early astronomers had really been guilty of an understatement. Castor, not content with being a twin, is itself sextuplets. The six stars are arranged in three couples. The two brighter couples are close together and revolving, and the two couples are revolving round one another. The third pair is the most interesting of all. It consists of two very small stars, both smaller and cooler than the sun, and this pair eclipses every nine hours, while at the same time it is swinging as a whole round the other four stars, taking millions of years to make the circuit. Imagine six stars, coupled in pairs, dancing for eternity in the depths of the firmament!

C.P.G.—The tiny eclipsing component of Castor is one of the reddest of eclipsing stars. But I cannot resist calling onto our stage another

red star—a variable with a difference. Your little red system consists of twin stars, both smaller than the sun. But my red friend is a thousand times larger. Indeed, if it were in the place of the sun, our little earth would be deep inside it. Even the distant planet Saturn would be immersed in its atmosphere.

S.G.—It is not difficult to guess which star you have in mind. There is only one VV Cephei. But I think you are leaving out the most interesting part. For your tremendous Gulliver has quite a small fellow as a companion. The two other eclipsing stars that we talked about might well be called twins. But in VV Cephei we find a physical connection between two extraordinarily different stars—a large red one and a small blue one. How did it happen that this gigantic system, that takes more than 20 years to complete its circuit, embraces such a contrast in components? Is it possible that this pair can have come into being in the same way as the systems of W Ursae Majoris and Castor C?

C.P.G.—Now you are really touching on the question: what is interesting about variable stars? We were becoming so interested in their variety that we had begun to lose sight of the original question. Do you think that astronomers have yet hit upon the answer to the question: how did eclipsing stars come into being—either twins or dissimilar pairs?

S.G.—Now indeed you have put me to the wall. Before you shoot I must express my personal opinion that we are as far away from the answer as we have been for centuries.

C.P.G.—Let us change the subject, then. We have been talking about our favorite variable stars—the Cepheids with their pulsations; the novae with their explosions—and the wide variety of eclipsing stars. We have been looking on them as individuals. One might say that we have been talking pure variable star astronomy. Now I should like to take up a more utilitarian point of view, and mention what we might call applied variable star astronomy. Not that astronomy has any application that can really be called utilitarian—that is one of its beauties—but the study of variable stars has some by-products that are of use for general astronomy, and even for physics.

S.G.—That point of view implies that variable stars are not abnormal. I would put it in this way: the variable stars, so to speak, open a door through which we can approach the other stars, which are made of the same materials, under much the same conditions, and are subject to the same laws.

C.P.G.—I can think of one application of variable stars that would provide a beautiful title for a thriller: "The Clue of the Winking Stars." Show me a photograph of the globular cluster Omega Centauri, and I can tell you the year, day, and hour at which it was made. The trick depends on the well-known fact that among its many hundred thousand stars, Omega Centauri contains two hundred variable stars—all with different periods, and all pulsating with such regularity that

they put our terrestrial timepieces to shame. It is easy to see that with these 200 stars, all varying regularly at different rates, the relative brightness will never be the same again as at one given moment. Theoretically it would be possible to deduce that moment from the relative brightness of the stars—but in practice it would be dreadfully laborious.

S.G.—I should like to suggest a less frivolous application. The speed of light in a vacuum is, in round numbers, 186,000 miles a second. When light is not travelling in a vacuum, the speed is reduced, and yellow light lags behind blue light. It is interesting to know whether light travels through interstellar space as if through a vacuum. Distant variable stars, with their periodic variations, provide a means of measuring the relative velocities of blue and yellow light, and it is found that blue and yellow light travel through interstellar space with the same speed, at least over an interval of several thousand years. This differential accuracy is far higher than that with which the velocity itself is known.

C.P.G.—Now we have applied variable star astronomy to two almost abstract problems—the measurement of time, and of the velocity of light. What about some more concrete applications of our knowledge?

S.G.—I should like to point out that we owe almost our whole knowledge of the sizes, masses, and densities of the stars to the study of eclipsing variables.

C.P.G.—I can think of only two exceptions. We have measured the size of the sun directly; and we have measured the sizes of a few stars —so few I can count them on my fingers—with the stellar interferometer. Otherwise you are right. We depend on eclipsing stars for our knowledge of stellar dimensions.

S.G.—It is lucky that almost all types of stars have been found as members of eclipsing systems—dwarfs, giants, and supergiants; hot and cool stars; stars with huge glowing atmospheres and stars with absorbing atmospheres. For we can only find out how large a star is by seeing it pass in front of another star.

C.P.G.—It would take too long and be too complicated, I suppose, to describe exactly how the sizes of the stars are inferred from the observed changes of brightness.

S.G.—It would indeed be long and complicated. The broad outlines are simple enough, but when one begins to get down to the details it must be admitted that the authorities are not even yet in full agreement.

C.P.G.—And it would be equally difficult to make clear in a few words how the masses of the stars, as well as their sizes, are heavily in debt to the eclipsing stars.

S.G.—In this case the eclipsing stars share the honors with the visual doubles, and, for both, the orbits must be supplemented by spectroscopic information. Accurate masses are known for less than 100 stars, approximate masses for about 400, and rough masses for several thousand.

C.P.G.—You have tacitly stated that the eclipsing stars are an important source of information about the densities of the stars. For if the

masses and the sizes are known, the mean densities follow immediately.

S.G.—That is a geometrical way of determining densities. We ought to say something about physical determinations of density.

C.P.G.—Now we are touching on the physical nature of variable stars. The intrinsic variable provides a method of determining stellar densities, but they are only relative densities. It is well known that if a star pulsates under gravitation, there must be a simple relation between the mean density of the star and the period of the pulsation. Roughly speaking, the denser the star, the shorter the period. More precisely—though still approximately—the period is inversely proportional to the square root of the mean density. Thus, for example, the mean density of CY Aquarii, the 88-minute star, must be about 100 times that of S Aurigae with its period of 578 days.

S.G.—Up to now we have spoken of the uses of variable stars in measuring the dimensions of stars. We ought now to describe their uses in surveying the Milky Way and measuring the Universe.

C.P.G.—The method depends on the fact that there is a relationship between the period of a Cepheid variable and its true or intrinsic brightness, so that if the period of such a star is known, its distance is known too. The long-period Cepheids are distributed all around and close to the Milky Way, some of them as distant as 6000 parsecs. But there are also a number of short-period Cepheids in high galactic latitudes, and at very considerable distances. In addition to outlining the shape of our Galaxy, the Cepheids are among the most useful means of measuring its rotation. They are bright, and therefore visible to great distances; and these distances are known. Therefore the determination of galactic rotation by means of the Cepheid variables is of considerable weight.

S.G.—You have spoken of the contribution made by the Cepheid variables to our knowledge of the structure and dimensions of the Milky Way system. Much more striking, to my mind, is their use in determining the distances of other systems beyond our own. It is obvious that if Cepheid variables of known periods can be detected in a distant stellar system, the distance of that system is known immediately. The Cepheids, for example, that were found in the Nebula in Andromeda showed immediately that this great spiral extragalactic system is distant about a million light years.

C.P.G.—Cepheid variables are not the only ones that can give an idea of the distance of a far-away galaxy. In some such systems, novae are not uncommon, and because they have been shown, rather surprisingly, to be approximately of the same brightness at maximum, they can be used for measurements of distance. It is interesting that some nebulae, such as the great spiral in Andromeda, are rich in novae, others very poor.

S.G.—And it must not be forgotten that the whole scale of distances in the Universe depends for its calibration on variable stars. Cepheid

variables and novae are the standard measuring rods of astronomy, against which other rods must be calibrated.

C.P.G.—But of course the standards had to be calibrated.

S.G.—The whole subject is a pyramid balanced upon its point—and that point is the zero point of the period-luminosity curve, which has been carefully determined from the motions of galactic Cepheids.

C.P.G.—Almost all that we have said up to now has related to the geometrical properties of stars or of galaxies. But I cannot refrain from mentioning a very special aspect of eclipsing variables, which gives us one of our few glimpses into stellar interiors.

S.G.—I know what you mean. You are referring to the fact that some eclipsing stars are revolving round one another in elliptical orbits. And that when such stars are near together, the interaction between them causes the whole orbit to swing around upon itself, thus leading to a complex motion of the component stars. The speed with which the elliptical orbit turns upon itself depends on the internal structure of the two stars, and in the hands of modern theorists it has been made to give information about that structure.

C.P.G.—That is a fascinating subject, but like many theories, it has at present not many facts to feed upon. There is no doubt about the existence of a few stars with turning orbits—rotation of the line of apsides, as the technical books have it—but there are less than a dozen well-determined cases. Here is a use for variable stars that has not yet been fully exploited. Many more cases must be found and thoroughly studied before it can be said that our knowledge of the internal structure of stars, based on apsidal motion, is in any sense complete.

S.G.—You have travelled rapidly in thought from the distribution and structure of galaxies to the inner structure of stars. Let us apply variable star astronomy also to the study of atoms.

C.P.G.—The loveliest example is the spectral development of a nova. When it begins to brighten, its spectrum is like that of an ordinary star —a bright background crossed by dark lines.

S.G.—But these lines are displaced far to the violet of their normal positions, showing that the surface of the star is swelling up as the star brightens.

C.P.G.—But the next stage is more surprising. Suddenly the spectrum is full of bright lines, almost if not quite all coming from the same atoms that gave the absorption lines. The transition is very sudden—usually it occupies only a few hours—and it is a little more than an idle metaphor to say that it signalizes the bursting of the star.

S.G.—The bright-line spectrum is interesting as being not unlike those of some high-temperature stars, which can be better understood by studying the nova transition.

C.P.G.—The bright-line spectrum of a nova then goes through a dramatic series of changes. At first it contains only lines that ordinarily occur in laboratory spectra. But after a short time it begins to

shine with the light of an aurora. The auroral lines are given by atoms at moderately low densities, and are produced by falling density as the envelope expands. Presently the nova begins to radiate light that is characteristic of nebulae—the so-called forbidden lines that are produced at even lower densities. The nebular lines become the strongest features of the spectrum, and may remain so for weeks or months. But finally they die away altogether, and very little is left in the spectrum of an old nova except some feeble bright lines.

S.G.—In other words, the nova shows us what atoms can do when the density falls and the temperature rises: first they give an ordinary absorption spectrum; then an ordinary emission spectrum; next they emit the auroral forbidden lines, then the nebular forbidden lines; and finally, when the succession of spectra has all but faded away, there is hardly anything left of the bubble, the superficial atmospheric bubble, that the star blew off.

C.P.G.—I wonder whether we have exhausted the possibilities of variable stars?

S.G.—I doubt it. But let us look forward to that discussion fifty years hence.

Planet Notes for July and August, 1941

By R. S. ZUG

NOTE: Greenwich Civil Time is employed unless otherwise stated. To obtain Eastern Standard Time subtract 5 hours, Central Standard Time, 6 hours, etc. The planetary phenomena are described as they are to be seen from latitude 45° N. The data are taken chiefly from the *American Ephemeris and Nautical Almanac.*

Sun. The sun will be moving through the constellations Gemini and Cancer during July. During the last three weeks of August it will be moving through Leo. The earth will reach aphelion point of its orbit on July 3.

Moon. Phenomena of the moon will occur as follows:

			h	m
First Quarter	July	2	4	24
Full Moon		8	20	17
Last Quarter		16	8	7
New Moon		24	7	39
First Quarter		31	9	19
Perigee	July	6	2	
Apogee		18	0	

Mercury. Mercury will be a conspicuous morning star for a few days preceding and following July 24, the date of greatest western elongation, when it will be situated in the configuration of the "twins" in Gemini.

Venus. The planet Venus is in the evening sky for about an hour after sunset during July and August. While its elongation from the sun is steadily increasing during this period, its declination is decreasing, so that the time of setting relative to the sun remains about the same. For the distance of the planet, its angular diameter, etc., reference may be made to page 30 of POPULAR

ASTRONOMY for January, 1941.

A conjunction of Venus and Neptune will take place August 18, 0^h, at which time Venus will pass 18′ to the south of Neptune. An occultation of Venus will occur August 25, visible in Asia, East Africa, India, and the Malay Archipelago, between extreme latitude limits 66° N. and 7° S. The G.C.T. of geocentric conjunction in right ascension is $7^h\,45^m3$. The occultation will occur in the daytime in the regions named.

Mars. On July 1 Mars will be found a little to the south of the vernal equinox in Pisces. The apparent motion of the planet from night to night will carry it in direct motion to a point just east of the star ν Ceti where retrograde motion begins on September 6.

Numerical data follow:

Date 1941	Distance from Earth (miles)	Angular Diameter	Declination	Stellar Magn.
July 1	73,900,000	11″8	−3°2	−0.4
15	66,273,000	12.1	−0.5	−0.6
Aug. 1	57,631,000	15.1	+2.3	−1.0
15	51,162,000	17.0	+3.9	−1.3
Sept. 1	44,431,000	19.6	+4.9	−1.7

From the above data it is seen that Mars will be a fine object for study during July and August as well as during the subsequent two months of close approach and opposition. A chart of Mars with accompanying information which will enable observers to identify the Martian longitude and latitude of the center of the planetary disk and the various surface markings visible at any time, may be found on pages 30-32 of POPULAR ASTRONOMY for January, 1941. A few reprints of this article "Planetary Phenomena in 1941" are still available and will be gladly furnished to anyone upon receipt of request and 2 cents for postage.

Jupiter. Jupiter is a morning star and will be almost in quadrature by September 1.

Saturn. Saturn is a morning object and will reach western quadrature on August 21.

Uranus. Uranus is a morning object and may be found shortly before dawn about 4° south of the Pleiades. A chart illustrating the apparent motion of the planet appears on page 34 of the January, 1941, issue of POPULAR ASTRONOMY.

Neptune. Neptune will be observed in the early evening sky until near the end of August when it will be too near the sun for identification. Its apparent motion among the background of faint telescopic stars is illustrated on page 35 of the January, 1941, issue of POPULAR ASTRONOMY. A conjunction of Neptune and Venus will occur August 18 as mentioned under the heading, *Venus.*

Asteroid Notes

By HUGH S. RICE

Ceres is observed with small telescopes during the summer months. At approximately 0^h E.S.T., June 4, this asteroid is in conjunction with the star Lambda Sagittarii, Ceres being about 7½′ north of the star. From this position it moves, in a retrograde direction, to a point about 1½° west of X Sagittarii (August 1). The average magnitude of the planet is 7.6; and opposition occurs

on June 23. The field is a rich one of the Milky Way, containing various Messier objects.

Pallas, much farther north, is also observable at this time. During the first week of June its place is about 4½° north of β Herculis. On July 1, it is 5° northwest of the star; on July 24, 5° west of the same star, or at the stationary point, after which it goes direct to a point 3° west of γ (August 5). Pallas' magnitude averages 8.9, and opposition takes place on June 1.

The subjoined ephemerides of 8 Flora, 20 Massalia, and 198 Ampella will aid the observer in locating the next brightest of the minor planets during the early summer. The ephemerides were computed by the Coppernicus-Institut at Berlin-Dahlem.

EPHEMERIDES OF ASTEROIDS, FOR 0ʰ U.T. EQUINOX 1950

	8 Flora	9M.2		20 Massalia	9M.9
	α	δ		α	δ
1941	h m	° ′	1941	h m	° ′
June 7	18 49.2	−19 34	June 23	19 30.3	−20 47
15	18 42.2	−19 58	July 1	19 22.8	−21 2
23	18 34.0	−20 24	9	19 14.7	−21 16
July 1	18 25.0	−20 51	17	19 6.5	−21 30
9	18 16.0	−21 20	25	18 58.8	−21 42
17	18 7.7	−21 48	Aug. 2	18 52.1	−21 53

	198 Ampella	9M.9
	α	δ
1941	h m	° ′
July 9	20 33.0	−10 3
17	20 26.4	− 9 25
25	20 18.7	− 8 55
Aug. 2	20 10.7	− 8 34
10	20 3.1	− 8 20
18	19 56.9	− 8 13

We list here the asteroids with the least and those with the greatest eccentricity of orbit of the known minor planets. It will be observed that those having the smallest values have very nearly circular orbits, in connection with which it is interesting to note that the earth's orbit has an eccentricity of 0.0167. As to the planets with large values, the table illustrates the fact that some of the values are greater than the eccentricities of certain comets. The data were compiled from elements of orbits, as determined by the Coppernicus-Institut.

ASTEROIDS WITH SMALLEST ECCENTRICITY

Asteroid	Eccentricity	Asteroid	Eccentricity
1262 Sniadeckia	0.0023	1389 Onnie	0.0179
1177 Gonnessia	0.0063	1481 1938 DR	0.0181
1300 Marcelle	0.0065	1266 Tone	0.0198
311 Claudia	0.0076	508 Princetonia	0.0201
1308 Halleria	0.0092	420 Bertholda	0.0201
1020 Arcadia	0.0095	338 Budrosa	0.0202
673 Edda	0.0110	452 Hamiltonia	0.0213
208 Lacrimosa	0.1116	147 Protogeneia	0.0217
1248 Jugurtha	0.0148	528 Rezia	0.0220
720 Bohlinia	0.0166	287 Nephthys	0.0224
196 Philomela	0.0177	799 Gudula	0.0230

ASTEROIDS WITH LARGEST ECCENTRICITY

Asteroid	Eccentricity	Asteroid	Eccentricity
.... Adonis	0.7792	1508 1938 UO	0.4194
944 Hidalgo	0.6557	699 Hela	0.4059
.... Apollo	0.5662	475 Ocllo	0.3839
719 Albert	0.5406	132 Aethra	0.3827
1036 Ganymed	0.5394	525 Adelaide	0.3710
887 Alinda	0.5388	898 Hildegard	0.3696
1474 1935 QY	0.4897	1006 Lagrangea	0.3599
.... Hermes	0.4746	1310 Villigera	0.3571
1134 Kepler	0.4718	1011 Laodamia	0.3506
1009 Sirene	0.4574	594 Mireille	0.3504
1221 Amor	0.4369	183 Istria	0.3495

Hayden Planetary, American Museum of Natural History,
New York, May 19, 1941.

Occultation Predictions

(Taken from the *American Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

Date 1941		Star	Mag.	IMMERSION Green-wich C.T.	*a*	*b*	Angle E from N	EMERSION Green-wich C.T.	*a*	*b*	Angle E from N
				h m	m	m	°	h m	m	m	°
OCCULTATIONS VISIBLE IN LONGITUDE +72° 30′, LATITUDE +42° 30′											
July	4	2 Lib	6.3	0 51.7	—1.6	—1.0	125	2 6.4	—1.7	—0.9	276
	4	4 G.Lib	6.5	1 30.7	—1.8	—0.6	93	2 44.0	—1.4	—1.7	304
	10	31 B.Cap	6.4	2 59.2	—1.4	+2.6	34	3 51.1	—1.5	—0.1	307
	10	τ Cap	5.3	9 37.4	..	..	6	10 4.9	..	..	317
	11	18 Aqr	5.5	2 51.2	—0.9	+2.0	56	3 57.5	—1.2	+0.9	278
	14	80 B.Psc	6.3	10 4.9	—1.6	+0.9	55	11 28.1	—1.6	—0.3	251
	15	155 B.Psc	6.5	9 49.3	—1.3	+2.2	34	11 6.0	—2.3	—0.6	272
	16	μ Psc	5.1	4 40.5	+0.1	+2.0	54	5 39.7	—0.4	+1.4	266
	31	96 Vir	6.5	0 45.5	—1.5	—0.6	76	1 46.9	—1.7	—0.5	297
Aug.	1	49 Lib	5.5	22 32.1	—1.7	+0.6	95	23 49.0	—1.7	—0.5	297
	2	90 B.Oph	6.5	22 27.8	—1.7	+1.7	68	23 30.0	—1.2	—0.5	315
	4	BD—18°5155	6.3	22 21.1	—0.7	+1.7	73	23 23.1	—0.8	+0.7	290
	5	187 B.Sgr	6.4	2 31.0	—2.0	—0.5	118	3 37.3	—1.6	+0.7	229
	16	70 Tau	6.4	5 26.9	+0.1	+0.6	77	6 27.3	—0.2	+1.6	256
	16	θ^1 Tau	4.0	6 59.9	—0.9	+0.8	113	7 54.2	—0.3	+2.8	217
	16	θ^2 Tau	3.6	7 22.1	..	..	158	7 30.0	..	..	172
	16	75 Tau	5.3	7 25.5	..	..	3	7 47.3	..	..	327
	16	264 B.Tau	4.8	8 6.0	—1.1	+1.5	87	9 22.1	—1.2	+1.9	242
	16	α Tau	1.1	11 48.5	—2.2	+0.1	88	13 19.2	—2.0	0.0	254
	18	124 H.^{1}Ori	5.7	9 9.2	—0.5	+2.5	56	19 13.9	—1.4	+0.4	292
	27	22 B.Lib	6.4	22 32.9	—1.7	—0.9	103	23 48.2	—1.4	+1.5	291

OCCULTATIONS VISIBLE IN LONGITUDE +91° 0′, LATITUDE +40° 0′

July	4	2	Lib	6.3	0 30.4	−0.9	−1.6	155	1 29.0	−2.4	+0.7	252
	4	4	G.Lib	6.5	0 58.5	−1.7	−0.5	117	2 17.4	−1.9	−0.8	288
	10	31	B.Cap	6.4	2 33.2	−0.8	+2.2	52	3 29.4	−0.7	+0.5	295
	14	80	B.Psc	6.3	9 32.5	−1.4	+2.2	36	10 51.7	−2.4	0.0	268
	15	155	B.Psc	6.5	9 24.8	−0.4	+3.7	10	10 17.3	−3.0	−0.8	296
	18	3	B.Tau	6.4	8 56.4	−0.2	+2.5	44	10 0.8	−1.2	+1.1	275
	31	96	Vir	6.5	0 12.0	−2.0	−0.4	96	1 28.8	−1.5	−1.7	307
Aug.	5	187	B.Sgr	6.4	2 0.3	−1.4	−0.2	128	3 0.4	−2.0	+1.7	228
	16	θ^1	Tau	4.0	6 49.6	−0.1	+1.0	101	7 44.6	0.0	+2.1	231
	16	θ^2	Tau	3.6	6 58.5	−0.5	+0.1	129	7 34.8	+0.4	+3.1	203
	16	264	B.Tau	4.8	7 50.5	−0.3	+1.8	74	8 58.1	−0.7	+1.6	256
	16	275	B.Tau	6.5	9 35.9	−1.3	+1.3	90	10 53.8	−1.4	+2.0	240
	16	α	Tau	1.1	11 8.3	−1.9	+1.3	80	12 38.7	−2.1	+1.0	252
	17	111	Tau	5.1	9 45.2	−1.2	+0.7	109	10 50.6	−0.9	+2.5	230
	18	124	H^1 Ori	5.7	9 1.2	+0.2	+2.6	44	9 50.6	−0.9	+0.2	303
	31	305	B.Oph	6.4	4 51.6	−0.7	−0.2	57	5 49.9	−0.9	−1.9	293

OCCULTATIONS VISIBLE IN LONGITUDE +120° 0′, LATITUDE +36° 0′

July	4	6	B.Lib	6.2	7 35.6	−0.9	−0.2	61	8 24.7	−0.8	−2.6	324
	14	80	B.Psc	6.3	8 55.7	−0.4	+3.9	8	9 36.6	−2.1	−0.6	305
	17	25	Ari	6.5	10 18.5	−0.9	+1.2	95	11 22.5	−0.6	+2.5	220
	18	3	B.Tau	6.4	8 52.6	+0.5	+2.4	30	9 34.7	−0.3	+0.4	296
	21	130	Tau	5.5	11 57.7	−0.2	+0.8	106	12 53.7	−0.1	+2.0	237
Aug.	4	Y	Sgr	5.8	9 14.1	−0.7	−0.4	66	10 15.4	−0.6	−1.4	278
	5	ρ	Sgr	4.0	9 50.9	−0.4	+0.7	37	10 41.6	−1.2	−2.2	297
	16	275	B.Tau	6.5	9 13.7	0.0	+1.7	70	10 17.2	−0.5	+1.4	261
	16	α	Tau	1.1	10 29.7	−0.4	+2.2	59	11 40.0	−1.3	+1.1	270
	17	111	Tau	5.1	9 27.6	+0.1	+1.2	90	10 26.7	−0.1	+1.6	249
	18	292	B.Ori	6.5	12 7.3	−0.9	+0.8	103	13 16.2	−1.0	+1.9	245
	29	49	Lib	5.5	5 40.9	−1.0	−1.9	123	6 36.2	−0.2	−0.5	247
	30	90	B.Oph	6.5	5 51.0	−1.1	−1.1	96	6 57.8	−0.6	−1.0	264
	31	305	B.Oph	6.4	4 13.3	−1.8	+1.2	44	5 13.6	−2.2	−2.3	312

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

In the past few weeks several reports of observations by our members upon the April Lyrids and the early May Eta Aquarids have arrived. The first seem to have been, as usual, in rather small numbers, but the Aquarids showed up well, as indeed they did last year. They are connected with Halley's Comet, which is now within seven years of its aphelion point. This proves a rather uniform distribution of meteors around the orbit, since they are found in good numbers when the comet is so far from perihelion, which was passed in 1910. The observations for 1941 now here will be discussed below.

Last month I finally brought my work on long-enduring meteor trains to a temporary close and gave a paper on the results before the American Philosophical Society. I then turned over the full manuscript to the secretary for submission to its publication committee. If published, I plan to distribute reprints to all active members of the A.M.S., many of whom have aided me by securing good data. Meantime it can be said that the tables contained information about 1336 trains which either lasted over 1 minute or, if a shorter time, showed definite drifts. Some of these data were never before published and, for the rest, refer-

ences as to where they may be found are given. I did not attempt to develop a new physical theory as to the reasons for their formation and persistence, as this should be done by a person trained in the most modern mathematical physics, but contented myself with drawing certain conclusions which have important astronomical or meteorological bearings. However, I assure everyone that I plan to continue the study of this subject in every way possible. To this end I ask the indefinitely continued coöperation of all observers in securing and fully reporting to me the appearance and behavior of any meteor trains which fall anywhere near the limits mentioned or which show motion. My experience to date convinces me that we have a subject of very great scientific importance whose investigation is as yet in its infancy. I would also appreciate references that they might find to such cases in the past, particularly in unexpected places. If I already have them, no harm is done; if not, they would be of great assistance in making our card files complete. Incidentally, the necessity for bringing the paper to a completion for the April meeting has been the main cause for the omission of some Meteor Notes in recent months.

As to the Lyrids, Chas. Tapscott of Champaign, Ill., observed April 24/25, 9:58 to 11:30 C.S.T., seeing 7 meteors, and on April 25/26, 9:40 to 11:30, seeing 10 meteors, F = 0.9 on both nights. He used Map 11 which covers a region rather far from the radiant. Out of the 6 plotted the first night, 2 are sporadic and the others uncertain. Out of the 10 on the second night, 5 are sporadic, 3 certainly and 2 probably Lyrids. A radiant cannot be accurately determined due to the difficulty of transferring from Map 11 to Map 7 where the radiant would be situated. He plotted 11 meteors on April 28/29 but this is too late for the Lyrids. Probable minor radiants, based on 3 meteors each and hence too few to be given AMS serial numbers, seem to be placed as follows: April 25/26, $\alpha = 222°$, $\delta = -8°$ and April 28/29, $\alpha = 159°$ and $\delta = +42°$, the first being the better determined. The Louisville, Ky., group observed April 20/21, 9:38 to 10:38, sky excellent. The counts were: Mrs. M. S. Landau 6 (2 plotted); J. Landau 7; W. L. Moore 8. The classes are not given, only one plotted meteor could be a Lyrid. R. M. Dole of Cape Elizabeth, Maine, reports that he worked from 11:00 to 13:00 (record not clear as to whether these hours refer to *every* night) and saw absolutely no Lyrid on April 18, 19, 20, 21, 22, and 23; skies excellent. He makes no mention of other meteors. In Connecticut, J. J. Neale reports for the New Haven group as follows: April 20/21, 9:25 to 11:20, partly clear sky, 7 meteors of which 4 were Lyrids; 5 plotted. H. Norton at N. Guilford counted 4, and R. T. Thompson at Madison counted 4 in same interval, class not given. The latter reports for April 21/22, 10:23 to 10:57, mostly clear sky, 6 meteors, 2 being Lyrids. Three groups of the Amateur Astronomers of the Franklin Institute here planned coöperative observations but clouds prevented.

For the Eta Aquarids, R. M. Dole observed May 4/5, sky excellent, 13:30 to 15:30, dawn interfering during last half hour. He saw 19 Aquarids, only one in first hour! There were 10 of 0 magn. or brighter. On May 6/7, sky excellent, and same hours, he saw 17 Aquarids, again only one during the first hour—a most strange coincidence. This night there were 4 of 0 magn. or brighter. I derive the following radiants from his maps:

AMS No. 4101 1941 May 4.62 $\alpha = 331°8$, $\delta = \ \ 0°0$, 19 meteors
AMS No. 4102 1941 May 6.62 $\alpha = 335°0$, $\delta = -0°5$, 17 meteors

Walter H. Haas at Columbus, Ohio, observed May 2/3, 14:13 to 16:04, F = 0.5, plotting 17 meteors, 4 being Aquarids and 2 of —2 magn. On May 3/4,

14:23 to 16:01, F = 0.5, he plotted 15 meteors, 4 being Aquarids, one of —4 and one of —2 magn. Due to the hazy skies on both nights he was only able to see Aquarids where their paths converged slightly, with a single exception. This prevents radiants from being determined from these maps. Incidentally, I have recommended Mr. Haas for a position as assistant at Flower Observatory for 1941-42. Several men, with whom I became acquainted through their AMS work, have received similar appointments in the past, and even more have gone to other observatories. The training that they received through their meteor work must have been at least in part responsible for their appointments. One group of the A.A. of F.I. from here observed for several hours on May 3/4, their station being at Riegelsville, Pa. They plotted 59 meteors but as the papers have not yet come into my hands the details cannot be given until later.

Recently I was pleased to receive a good report from K. Komaki of Kanaya, Japan, covering, for 1940, observations on July 28/29, July 29/30 and Aug. 13/14, in all 55 meteors. Also for 1941, work on Jan. 3/4, 16:10 to 16:40, F = 0.2; 6 meteors; and on Jan. 4/5, 15:22 to 17:52, F = 1.0, 41 meteors. On projecting the plotted paths backwards on the maps a glance shows no sharp radiant but a diffused area. It will take considerable time to study this properly, so the radiant determination must be postponed. I have also received letters and reprints from other Japanese observers recently. It seems most useful to everyone to try to maintain cordial scientific relations.

A detailed report comes from Prof. Mohd. A. D. Khan of Begumpet, Deccan, India, probably the most active observer we now have. This consists of record sheets covering the period 1940 July 6 to Dec. 31 inclusive, with serial numbers 1940, 481 to 1390. The results show what an immense amount of observing he did, as he utilized 65 nights in this interval. As undoubtedly he is a man fully occupied with official duties, this indicates what can be accomplished by a person whose heart is in the work. Instead of sending the maps, he has entered the coördinates of the ends of each meteor path in the appropriate columns. Unfortunately, not until these are replotted—a great task!—can the radiants be found. This procedure is not recommended as it both took more time for him to derive the coördinates than it would have taken to trace the paths on a second set of maps, which we would and do gladly furnish, and there will be indefinite delay here until I can find someone with time and skill enough to replot from the coördinates. However, for a study of rates derived in a country where regular meteor work has seldom been undertaken and for other statistical uses, the data are immediately available and I congratulate Prof. Khan on being by far our best observer for 1940.

As we can hardly expect much from the Pons-Winnecke meteors in June, their orbit apparently having been shifted outside ours, the Delta Aquarids of late July and the excellent Perseids of August are the next prominent showers. Will all active observers write, well in advance, for such maps and blanks as they will need in the summer.

The Flower Observatory has several hundred copies of 8 out of the 11 Parts of the first four Volumes of its *Publications*. We would gladly furnish amateur astronomers or libraries with such sets for the cost of postage or express. One dollar for those within 1000 miles and $1.50 for the rest of the country should be sufficient. On receipt of a request, with this cash enclosed, we will send the publications mentioned. The subjects covered are mostly double stars and zenith telescope work. Volumes V and VI, published since 1930, are available in such

small numbers that they can be distributed only by regular exchange or to persons on selected lists.

Flower Observatory, Upper Darby, Pa., 1941 May 15

Contributions of the Society for Research on Meteorites

Edited by **FREDERICK C. LEONARD,**
Department of Astronomy, University of California, Los Angeles

President of the Society: H. H. NININGER, Colorado Museum of Natural History and American Meteorite Laboratory, Denver

Secretary of the Society: ROBERT W. WEBB, Department of Geology, University of California, Los Angeles

Free Copper in a New Aërolite from Garnett, Kansas

By H. H. NININGER

ABSTRACT

The occurrence of free copper in a new aërolite from Garnett, Kansas, and the aërolite itself are described. To the writer's knowledge, this is but the third time that free copper in a meteorite has been reported. It has been previously detected in specimens of the Richardton, North Dakota (aërolitic), and Xiquipilco, Mexico (sideritic), falls. The largest copper nodule discovered in the Garnett stone has about 25 times as great an exposed surface as had the most sizable fragment reported earlier, measuring 2.0 × 0.6 mm. Since the original writing of the paper, several small grains of free copper have been found in cutting a 9-lb. individual of the Xiquipilco fall. As free copper is probably present in irons other than those from Xiquipilco, a method of searching for it is outlined. A chemical analysis of the Garnett stone, by F. G. Hawley, is included.

On Saturday, February 13, 1939, the American Meteorite Laboratory exposed the largest mass of free copper ever reported in a meteorite—a mass which is, by measurement, about 25 times as large in area of exposed surface as the largest previously reported. Free copper was first announced by T. T. Quirke (*Econ. Geol.*, **14**, 619, 1919), who described 3 small specks of this metal in one of the metallic veins of a Richardton, North Dakota, aërolite, which fell on June 30, 1918. The largest bit was described as being 0.6 × 0.08 mm. in exposed section. The second report of free copper, as far as the writer is aware, was made by John Davis Buddhue (*C.S.R.M.*, **1**, No. 3, 7-10; *P. A.*, **45**, 103-6, 1937), who found a small spheroidal mass embedded in a dark, supposedly troilite nodule, in a nickel-iron meteorite assigned provisionally to the Xiquipilco, Mexico, fall. Copper is nearly always reported as being present in metallic meteorites, as determined by chemical analysis, but always in very small quantities, and never, except in the single case mentioned, as free metal.

The subject of this paper appeared in a new stony meteorite discovered near Garnett, Anderson County, Kansas, and reported to our Laboratory by Mr. P. A. Hardesty, who plowed it up from his field in 1937. The stone weighed 4788 g. when received at the Laboratory and it appeared to be complete, except for a few small chips and one small, end piece that had been removed. Its original weight must have been less than 4900 g. The stone was old and badly weathered. In

fact, before cutting it, we prized it chiefly as an example of the manner in which meteorites come to be indistinguishable from terrestrial rocks. One of the men who has for several years been intimately associated with the American Meteorite Laboratory averred that he would never have recognized the specimen for what it was if he had seen it in the field! Mr. Hardesty deserves great praise for recognizing such a specimen, even in a region where terrestrial rocks are very scarce. About a year previous to the finding of this stone, the writer delivered a number of lectures in the schools in and about Garnett and distributed literature freely. This discovery followed that educational effort, as have the majority of our finds in various localities.

Though so deeply weathered that apparently all of the original fusion crust was concealed by alteration products, the specimen showed no indication, externally, of fracturing or of exfoliation, but, where chipped, the dark interior was seen beneath a porous, light-brown zone, varying in thickness from 2 to 5 mm. In this respect, as well as in the color and the texture of its interior, the aërolite strongly resembled the McKinney, Texas, stone (discovered in 1870); it was a roughly 4-sided, elongated block, with some noticeable pitting on one side, a rather rough opposite side, and the 2 alternate surfaces convex and rather smooth.

After sectioning and polishing, noticeable fractures were found traversing the slices. These fractures varied in width from almost 1 mm. to microscopic dimensions. Some of them differed from those usually seen in aërolites in being filled with distinctly reddish material instead of the black filling which is commonly found. Others contained a yellowish-brown filling resembling the weathered crust which covered the specimen, while still others contained the blackish material of the type most common to weathered aërolites. An abundant network of this last-named type, mainly of very small dimensions, permeated the mass. These tiny fractures were compactly filled and were visible, accordingly, only as minute blackish or reddish lines and not as cracks. The polished slice inside the conspicuous border of light-brown crust appeared as a dark, greenish-black mass of almost uniform color and texture between the fissures and veins just described. It was richly studded with minute, irregular grains of nickel-iron and sulfide, resembling the Gladstone, New Mexico, aërolite in the matter of size, form, and abundance of these constituents. Occasionally, a nickel-iron grain was found which was much larger. One measured 1 mm. in width and was 8 mm. long. The greenish tint of the matrix, however, more closely resembled that of the Melrose, New Mexico, and McKinney, Texas, aërolites. Under a lens, the matrix was found to consist almost entirely of chondrules which varied in size from several mm. to microscopic dimensions. For the most part, they were circular in cross section, but some were elliptical or oval and several fragmentary ones were noted as crescents, half-circles, or less complete forms. The chondrules varied but little in color and appeared to consist almost uniformly of olivine. However, none has as yet been actually tested mineralogically. A few stood out noticeably blacker than the rest.

Free Copper in the Aërolite

On the slice that is before me as I write, the most conspicuous feature is an included mass of metallic copper large enough to be easily recognizable when viewed from as great a distance as that across the table. It measures 2.0 × 0.6 mm. and constitutes about two-thirds of a nodule, the remainder of which appears to be troilite (see the figure). However, upon close inspection under a × 10 lens, a second inclusion of copper is found within this sulfide end of the nodule. No

other free copper is found by going carefully over the slice with a hand lens. The nodule in which the red metal appears lies 24 mm. from the edge of the slice and is associated with one of the fissures described previously. Measuring along this fissure, I find that the nodule is 32 mm. from the edge of the slice. There seems to be no possibility that the copper reached this location from the outside. It belongs evidently to the specimen.

FREE-COPPER INCLUSION IN THE GARNETT AËROLITE, × 3½
(The light-colored portion of the nodule in the photograph is the copper. The broken line across the nodule marks the border of the copper.)

Unfortunately, the slice was ground by an assistant who had not before worked in our shop and who did not appreciate the importance of this copper nodule. When finally it was called to his attention by the shop foreman, Mr. Harold Rothrock, the assistant said that he had noticed it for some time and that it was considerably larger during the earlier stages of the grinding. We can only regret this loss! Later, other slices were cut from the Garnett stone, and on several of them copper was revealed, but in very much smaller particles than the one herein described. Evidently this metal is widely disseminated through the meteorite. The chemical analysis shows a somewhat higher content of copper than is commonly found.

Since the original preparation of this paper, our Laboratory has discovered several small grains of free metallic copper in cutting a 9-lb. iron from the Xiquipilco, Mexico, fall. These grains were very irregular in form and were found in most cases in association with graphite and schreibersite, where these two minerals came together in surrounding troilite and graphite nodules. More than a hundred slices of specimens of this great shower of meteorites have been cut, polished, and etched in our Laboratory. In none of them had copper previously been found.

Free copper is probably to be detected in other nickel-iron meteorites than those of Xiquipilco, but it has doubtless been overlooked. For the benefit of persons who may care to examine the irons in their collections for possible inclusions of the red metal, I would suggest that they carefully inspect, under a × 10 lens (a binocular microscope is even better), all of the nodules, especially those where graphite inclusions are associated with schreibersite and troilite. Care should be taken not to confuse certain varieties of the oxides of iron, which appear to be of

almost exactly the same color as the copper. These iron-oxide inclusions may be readily distinguished by the use of a dissecting needle. Under the prodding point of the needle, the copper appears very ductile, while the oxides are brittle.

Following is the chemical analysis of the Garnett meteorite as submitted by F. G. Hawley:

FeO	17.94%	MnO	0.39%
Fe_2O_3	3.58	CaO	1.96
NiO	1.42	MgO	25.31
CoO	0.11	Alkali	1.05
CuO	0.09	SiO_2	39.46
Cr_2O_3	0.55	P_2O_5	0.31
Al_2O_3	2.30	FeS	5.06
TiO	0.11		

The metallic portion equalled 10.1% of the whole mass analyzed. The analysis of the metallic portion gave:

Fe	86.21%	Insoluble material present	7.00±%
Ni	6.54		
Co	0.38	Pt metals	0.06 oz. per ton
Cu	0.12		

The Need for an Institution for Research on Meteorites

By Frederick C. Leonard

Millions of dollars have been spent and millions more are being annually appropriated for all kinds of scientific research with one exception. That exception is the study of meteorites. It is almost incredible that the only tangible objects of astronomical inquiry have been so sadly neglected for so long a time. Even as we enter the fifth decade of the twentieth century—nearly a hundred and forty years since the fall of meteorites to the Earth was first demonstrated to the satisfaction of scientific men—there is not an institution in the world (with the doubtful exception of one in Russia) that provides for a chair of meteoritics. There is no endowment anywhere (at least in the United States) sufficient to permit even one man to devote himself to the pursuit of this important subject. Permanent endowments and current appropriations for scientific research run into many millions of dollars annually; yet, to my knowledge, there has never been made available for the study of meteorites a single grant, adequate to pay the salary of a competent investigator during one year!

Meteoric astronomy has fared a little better, but even in this field funds have been pitifully scarce. It is apparently easier to raise millions of dollars for the construction of larger and larger instruments with which to probe farther and farther *into* space than to secure the few thousands necessary to carry on systematic investigations of the only materials that ever reach us *from* space! This neglect of the study of meteorites cannot be ascribed to any lack of promise on its part to yield significant results. Even with insufficient funds, the few persons who have been devoting a portion of their time and energy to research on meteorites have discovered some really astounding facts. They have showed that many of the generally accepted notions concerning the constitution and the composition of meteorites, their age, their frequency of fall, their tridimensional distribution, the weight of their increment to the Earth, *et cetera* are grossly in error. Conclusions regarding these matters are of fundamental importance in several of the sciences, yet the responsibility for establishing them is left almost entirely to the few investigators who are willing to skimp and to sacrifice even the common

comforts of life in their endeavor to add bit by bit to our meager store of knowledge in this field.

Enough is now known about meteorite craters to make it certain that no authority is at present in a position to evaluate, within hundreds of percent, either their total number or their range of size on this planet. Under these conditions, their astronomical and geological significance can be discussed in terms of only the wildest speculation. We have abundant evidence to show that a proper approach to this question, like that commonly followed in other field problems of geology, would yield the requisite data for a correct appraisal of meteorite craters as a factor in the evolution of the Earth; yet both geologists and astronomers have failed, thus far, to take even the first steps toward making a thoroughgoing investigation of the matter.

I know of a State university where, for sixty years, the geological staff has been attempting by field expeditions again and again to determine the exact boundary of the terminal moraine of the Keewatin ice sheet. In the course of those six decades, the "shifts" in the "limits" of the glacier have amounted to only a few miles; yet, when another deposit of erratics shall become uncovered by erosion, still another change in the "boundary" will have to be made! In that same State, studies of meteorites have produced results indicating that the meteoritic increment to the area is *several thousand times* as great as that quoted in the geological textbooks in current use in the university; however, it is doubtful whether that university, during its entire history, has expended as much as a hundred dollars on the study of meteorites!

One of the most active investigators of meteorites found it necessary, about ten years ago, to choose between giving up his life work in this field and relinquishing his professorial position in a college where, as a teacher, he was an outstanding success. After he had ascertained that no institutional funds were available for the prosecution of meteoritical research, he made the courageous attempt to finance his own program. How he has managed to carry this on during more than a decade now is a puzzle even to those who know him best and—as he admits—sometimes even to himself! His results, as reported in nearly a hundred published papers, leave no doubt about the success of his efforts or the extraordinary promise that the field of meteoritics offers in return for a properly supported program. Other men who, while continuing to teach and to do research in other lines, have devoted a part of their time to investigations in meteoritics, have achieved results in proportion. Probably no other field in astronomy or geology gives promise of such a rich harvest of meaningful data as does the field of meteoritics; yet certainly no other is less intensively cultivated and less adequately financed!

Lack of space prevents more than a passing reference to the amazing results that have been accomplished through the use of various kinds of meteorite-detecting devices. One of the most important advances in meteoritics has come, within just the last few years, from the application of these remarkable instruments, which have opened up literally a new dimension in the realm of meteoritical exploration. Thanks to meteorite-detecting apparatus of one sort and another, we are no longer confined to the surface of the ground in our search for specimens, but are able to penetrate the soil to depths of many feet in quest of them.

There are at least a dozen avenues along which a program of meteoritical research would lead to results of direct practical benefit to mankind, while the contributions that the study of meteorites can make to the solution of some of the

most profound problems in astronomy and geology are legion.

As an astronomer who has had a life-long interest in meteorites, who has made a few investigations of them, and who has participated in the organization and the direction of the Society for Research on Meteorites—an active, international union of a hundred and fifty members, mostly professional scientists, affiliated with the American Association for the Advancement of Science; as one who has witnessed the heroic struggles of the workers who have pioneered in this neglected field and have sacrificed and suffered almost to the breaking point; and as one who, from personal knowledge, can bear testimony to the scientific value and the practical utility of meteoritical research, whenever and wherever it is undertaken with skill and with enthusiasm, I would say to those who have the privilege and the responsibility of arranging for the disposition of bequests, that there is no more worthy and no more timely object to which such funds could be applied than a program of research in meteoritics. Here is a field that is unique—one that should appeal to both the layman and the scientist, and one in which future discoveries are destined to become an integral part of the very foundations of two of the noblest of the sciences—astronomy and geology.

Unquestionably the greatest need of meteoritics today is the need for an institution, adequately endowed and dedicated primarily to the prosecution of systematic and continuous research on meteorites and meteors. The value that would ensue from the establishment of such an institution, not only to meteoritics but to its parent sciences, cannot be overestimated.

The Eighth Meeting of the Society

As announced in previous issues, the Eighth Meeting of the Society will be held at Flagstaff, Arizona, on June 23, 24, and 25, 1941. The scientific sessions will be open to the public and guests as well as members will be welcome. Members who intend to contribute papers to the meeting, either in person or *in absentia*, are requested kindly to have the titles of their communications in the Secretary's hands *not later than June 10*, so that all titles may appear on the program.

The Museum of Northern Arizona, the Lowell Observatory, and the Arizona State Teachers College will be the institutional hosts at this meeting. The first general session will open in the Administration Building of the College, which is a short distance south of the center of Flagstaff, at 9:00 o'clock on Monday morning, June 23.

ROBERT W. WEBB, *Secretary*

A Practical Application of Meteoritics

Under the heading, "Metal Congress will study Meteor[ite]-like Steel Process," the following "story" appeared in *Los Angeles Times* for April 20, 1941:

"Study of iron and nickel meteor[ite]s, by which science [has] learned to reduce crystallization of automobile steel, has been programmed for the Western Metal Congress, May 19-23, in Pan-Pacific Auditorium and the Biltmore.

"W. H. Eisenman, Secretary of the American Society for Metals, said [that] microscopic examination showed [that] the molecular structure of meteor[ite]s underwent change during the heat treatment the 'shooting star' received in passing through the Earth's atmosphere.

" 'Metallurgy has learned to duplicate this heat treatment,' he continued, 'and can rearrange the inner crystals of steels so that they are virtually immune to fatigue.'

"The Congress will be attended by 3000 technical engineers, many of them engaged in national-defense projects. An exhibit of scientific metal apparatus in the auditorium will accommodate more than 50,000 metal workers."

The Halley Lecture for 1940 on Meteorites

The Halley Lecture of the University of Oxford (England) for the year 1940 was delivered on 16 May 1940 by Dr. F. A. Paneth, Professor of Chemistry in the University of Durham, on "The Origin of Meteorites." The lecture has since been published at the Clarendon Press, Oxford, as a 26-page brochure with 3 half-tone plates.

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

By LEON CAMPBELL, Recorder

Increase in Brightness of χ Ophiuchi: Mr. Joseph Ashbrook of the Warner and Swasey Observatory reports that the Be star, χ Ophiuchi, is at least four-tenths of a magnitude brighter than the magnitude quoted in the Revised Harvard Photometry, $4^{M}.85$. Observed magnitudes of the star are listed in *Harvard Annals* **14**, **24**, **44**, and **46**, with values of 5.03, 5.11, 4.72, and 4.54, respectively. Residuals in the individual volumes are quite small, indicating an excellent agreement for each epoch of observation.

The star was evidently fainter—magnitude 5.0— in 1880 when the observations of *H. A.* **14** were made, and somewhat brighter—magnitude 4.5 to 4.7—when observed around 1890. In April and May of 1940, Ashbrook gives the magnitude as 4.4, and for April and May, 1941, the magnitude is also 4.4.

χ Ophiuchi is to be found in Merrill's list of Be stars, of which γ Cassiopeiae is also one that has in recent years been found to change in brightness by more than a magnitude. χ Ophiuchi should be observed for further evidence of variability.

Peculiar Variations of RX Andromedae: The peculiar Z Camelopardalis-type star, RX Andromedae, which usually presents irregular fluctuations of light between magnitudes 10 and 13 in a mean cycle of 14 days, has recently shown a very small amplitude of variation—between 11.4 and 12.2, frequently even less—over a rather protracted interval of time.

The last occasion on which RX Andromedae attained the magnitude 11.0 was in September, 1939, and a magnitude brighter than 11.0 has not been reached since May, 1938. During the past year and a half there has been little evidence of the 14-day cycle. A perfectly irregular series of small fluctuations only has been observed. This period of irregularity, at a brightness somewhat near the median magnitude, is one of the longest on record.

U Geminorum Stars, Recurrent Novae and Ordinary Novae: The ever increasing observational data which are being secured on the U Geminorum-type stars, including their near relative the Z Camelopardalis-type stars, appear to be providing additional evidence of a close tie-up with recurrent novae, and possibly

with normal novae. There seems to be a well-established correlation of amplitude with length of cycle which cannot well be disputed.

The Z Camelopardalis stars have amplitudes of variation which are confined to between two and a half and three magnitudes, and average cycles of from 12 to 25 days. Stars such as SS Cygni and SS Aurigae have amplitudes approximating four magnitudes and average cycles of 50 to 55 days. U Geminorum, with an amplitude of five magnitudes, presents still longer cycles, around 120 days. We have at least three well-known cases of recurrent novae—RS Ophiuchi, T Pyxidis, and U Scorpii. The first mentioned had two outbursts in an interval of 35 years, with an amplitude of approximately eight magnitudes. T Pyxidis had three observed maxima in intervals of 12 and 18 years, and 21 years have elapsed since the last outburst, with the nova still at normal minimum magnitude. This star has an amplitude of 6 to 8 magnitudes. U Scorpii also presented three maxima, in 1863, 1906, and 1935, with an amplitude probably greater than eight magnitudes.

If we plot the amplitudes against the logarithms of their average cycles, we obtain a fairly representative correlation between them which would indicate that if all normal novae are recurrent, as has been suggested on occasion, then they would reappear as bright stars on the average of once in 70,000 years, if they also have an average amplitude of 13 magnitudes. This correlation is by no means a newly discovered one, for Kukarkin and Parenago in 1934 called attention to this feature in a Russian publication of that year. The Gaposchkins also refer to the possibility of such a correlation in their book, "Variable Stars." Although the length of cycle for the possible recurrence of an outburst of a normal nova may not be too accurately extrapolated from the data at hand, we may well assume that such a recurrence will require many thousands of years, rather than hundreds or a few thousand years.

There are other indications that U Geminorum stars and the recurrent novae may be closely allied to normal novae, especially when their spectral characteristics are considered.

An added feature in connection with the Z Camelopardalis and the U Geminorum stars is that for those of longer cycles and greater amplitudes, there is less erratic behavior in the form of maximum. For example, the very short cycle Z Camelopardalis stars increase to maximum at very irregular intervals and hardly any two maxima follow the same pattern.

For SS Cygni—mean cycle 50 days—not only do "short" and "long" maxima occur, but there are occasions when the so-called "anomalous" maxima appear with a long drawn-out increase to maximum, and frequently with maxima of very long duration. For SS Aurigae—with a period only slightly longer than that of SS Cygni—the anomalous maxima are of very infrequent occurence, and for U Geminorum itself—with a cycle two or three times that of SS Aurigae—an anomalous type of maximum has never been observed. The alternation of "short" and "long" maxima for SS Aurigae and SS Cygni is never maintained for more than a few cycles. For U Geminorum the alternation of short and long maxima is the rule, rather than the exception.

For the recurring novae it was shown that the maximum of RS Ophiuchi in 1898 could be almost exactly superposed on the maximum of 1933, with few, if any dissimilarities. The three observed outbursts of T Pyxidis—with shorter cycles than for RS Ophiuchi—did not follow the same pattern of light curve. If normal novae ever do have more than a single outburst, it would be of interest

to note whether or not the second outburst follows the same form of light curve as the first one. Only future generations can expect to see further outbursts of normal novae!

Variables in Globular Cluster, M4: Dr. A. de Sitter at the Bosscha Observatory in Lembang, Java, has recently published a preliminary report on his discussion of variables in Messier 4, a cluster which has also been studied by Helen Sawyer. De Sitter lists 26 variables, giving periods, epochs of maximum, and range of variation. Messier 4 shows the usual sharp distinction between Bailey's type c and types a and b. Type c gives a mean period of $0^d.297$ and the mean period for the a and b types is $0^d.530$. Type c comprises 23 per cent of the 39 variables of known period, thus closely agreeing with the percentages found in Messier 3 and Messier 5.

Variable No. 6 in Messier 4 is considered by de Sitter to be of the W Ursae Majoris eclipsing type and he presents a light curve derived from his own estimates.

Photoelectric Photometry of 44 i Bootis, B: V. B. Nikonov has recently published in the Bulletin of the Abastumani Astrophysical Observatory a discussion of his observations of 44i Bootis, B, as made with two types of photocells, caesium-oxide and stibium-caesium, which measure the light in the infra-red and violet regions of the spectrum, respectively. The star was observed in 1935-1936 with a potassium-hydride cell by W. A. Calder, who found slight differences in the shapes of the curves for each year. Nokonov suspects that κ Bootis, used as a comparison star by Calder, is itself subject to variation and accordingly he used BD $+ 50° 2126$ as a comparison star.

The period of 44i Bootis, B, the fainter component of the double star Σ 1909 = ADS 194, is short, around a quarter of a day, and a complete light curve can usually be observed on a single night. The variable is of the W Ursae Majoris eclipsing type. The two light curves obtained by Nikonov, and that of Calder, with very different spectral sensitivities, are practically identical. Nikonov believes, in view of the fact that his light curves as observed with two different types of photocells did not reveal any noticeable changes in the shape of the curve, and that they agree so well with Calder's mean light curve, that the slight variation found between 1935 and 1936 by Calder may be due to a possible variation in the comparison star κ Bootis. The close agreement of the light curves in quite different regions of the spectrum shows that for this eclipsing variable there is a close similarity in the structure of the two components.

The Eclipsing Variable WY Tauri: The variable star WY Tauri when first announced as variable by A. S. Williams in 1922, was classified as a Cepheid with a period of a third of a day but with a secondary minimum—something very unusual for a Cepheid with a period of less than one day. For many years the star continued to be considered as a Cepheid. Williams' published light curve of 1925-1926 would certainly lead one to conclude that the star was a Cepheid of the RR Lyrae type. Miss Balazs in 1936 assigned a period of $0^d.34620$ with a range in magnitude between 11.10 and 11.63 and was the first to call attention to the eclipsing nature of the variable.

From a study by Miss Balazs and Detre of a long series of photographic observations made in 1937-1939 and measured with a Rosenberg microphotometer it is found that the star is of the eclipsing type with two minima—they call it Beta Lyrae but perhaps W Ursae Majoris would be a better term—with a period of $0^d.69$ and with a secondary minimum only $0^M.06$ brighter than the primary mini-

mum. They present an interesting discussion of the star in a paper recently published at the Budapest Observatory, in which they derive the following elements of the system:

Period	$0^d.6927580$
Phase of secondary minimum	0.5 P
Duration of eclipse	$0^d.153$
Magnitude at maximum	11.09
Magnitude at principal minimum	11.63
Magnitude at secondary minimum	11.57
Inclination of orbit	73°53′
Ratio of radii	1.00
Effective ellipticity of components	0.300
Major axis of components	0.372*
Ratio of minor to major axis of components	0.886
Relative luminosity of fainter component	0.454
Relative luminosity of brighter components	0.546
Density of components (equal)	0.346 ⊙

*Distance between centers.

Observers and Observations received during the month of April:

Observer	Var.	Est.	Observer	Var.	Est.
Albrecht	16	24	de Kock	62	278
Ball, A. R.	23	44	Koutz	44	59
Blunck	13	19	Livingston	46	57
Bouton	38	57	Manlin	18	38
Brocchi	10	10	Maupomé	50	62
Carpenter	8	8	Milnes	12	18
Cave	17	46	Moore	4	4
Chilton	2	2	Nadeau	8	9
Cilley	52	104	Parker	19	19
Cousins	41	102	Parks	22	42
Dafter, Mrs.	8	23	Peltier	108	178
Diedrich	14	19	Prinslow	7	7
Ferguson	3	4	Purdy	5	5
Fernald	115	204	Roe	2	3
Ford	10	10	Rosebrugh	13	36
Forrester	9	11	de Roy	10	41
Griffin	30	30	Saxon	46	61
Halbach	83	101	Schoenke	22	31
Harris	36	36	Sill	50	51
Hartmann	106	173	Smith, F. P.	9	12
Hildon	14	24	Stahr, Miss	9	11
Holmes, Mrs.	6	6	Taulman	28	49
Holt	126	323	Topham	92	135
Houghton	69	69	Walton	12	17
Irland	14	16	Yamasaki	48	48
Kearons, Mrs.	75	175			
Kelly	19	20	52	Totals	2931

May 14, 1941.

Comet Notes

By G. VAN BIESBROECK

No known comets are at present in reach of ordinary astronomical instruments. Recently while at the McDonald Observatory, Fort Davis (Texas), I succeeded in making a first observation of periodic Comet 1925 II (SCHWASSMANN-WACHMANN I) which is now emerging from the vicinity of the sun. The faint image of the comet was identified on two plates taken before dawn on April

30. The comet appeared as a tiny round coma, some 10″ in diameter and not brighter than a star of magnitude 18. The following ephemeris by Behrens (*U. A. I. Circ.* 832) indicates the position of this object:

1941	α h m	δ ° ′
May 30	22 13.9	−11 11
June 7	15.3	10 57
15	15.9	10 45
23	15.8	10 38
July 1	15.1	10 35
9	13.7	10 35
17	11.6	10 37
25	8.9	10 44
Aug. 2	22 5.7	−10 53

The above observation gave for the correction of the ephemeris:

April 30 $\alpha + 0^m.8$ $\delta - 4'$

Observations would seem difficult on an object as faint as this. It should be remembered, however, that this curious comet has shown very large and sometimes rapid fluctuations in brightness in the past; sometimes it has brightened up by several magnitudes in a couple of days so that it is well worth watching the region in which the object is located.

By the end of this month Comet 1941 *c* (PARASKEVOPOULOS) will have moved away sufficiently from conjunction with the sun so as to again become observable in the night sky. But its magnitude will of course be reduced very much since the bright apparition last winter. The following ephemeris by J. Bobone (*Harv. Ann. Card* 579) will locate the object in the morning sky. The computed magnitude is uncertain and the comet may well be fainter than is indicated.

0^h UT	α h m	δ ° ′	Mag.
1941 May 30	2 28.4	+16 57	11.8
June 7	29.2	17 26	12.0
15	29.4	17 51	12.2
23	28.6	18 13	12.4
July 1	2 26.7	+18 32	12.5

Williams Bay, Wis., May 12, 1941

Notes from Amateurs

The Joliet Astronomical Society

The Joliet Astronomical Society resumed regular meetings in October under the leadership of Dr. Walter B. Huey, who thus became our first third-term president. Dr. Huey and Mr. Paul Ohman began the construction of an observatory at Little Palomar, the site secured through the efforts of Mr. Ohman. The building will house a 12-inch reflector now under construction. The site has been used for some time for observation parties which are open to the public.

Extensive plans were made for the observation of the transit of Mercury on November 11. Two groups practiced under the direction of R. D. Cooke, one using the Junior College refractor and the other using Mr. Cooke's reflector. Stormy weather prevented the observations.

Mr. Cooke computed about one hundred occultations visible in Joliet during

the present year. Some successful observations have been made and, on April 1, the occultation of Aldebaran was viewed by the members during a regular meeting.

The society again recognized the observance of National Education Week by setting up an exhibit consisting of astronomical literature, transparencies, steps in making a mirror, and some mechanical teaching aids. Many guests of the open house of the Joliet Township High School and Junior College viewed the planets then visible through the Junior College instrument.

The Misses Alice and Margaret Dombrowska opened their beautiful home to the society on the occasion of the annual Christmas Tea. Some fifty members and friends enjoyed an evening of carol singing, astronomical games, and some items of a serious nature. Van Dyke's story of "The Other Wise Man" was told by the secretary, Miss Syblie Gibson. Colored movies of the guests were taken by Frank M. Preucil while movies of other years were shown by the sponsor.

A trip to the Adler Planetarium in Chicago at the invitation of the Director, Miss Maude Bennot, was made on April 22. Some fifty members and students heard Miss Bennot give the current lecture on the moon and eclipses and all felt that she covered the subject in a most thorough and charming manner.

As usual, the society provided speakers for a number of organizations during the year. The loss of two valued members was recorded: Mr. William S. Buttles of Chicago and Geo. R. Hill of Joliet.

The formal work of the society closed with the annual banquet on May 20, when the officers reported on the activities of the year and announced the summer schedule of observation.

Members have taken an active part in the drive to establish a Museum in Joliet. Ben Hur Wilson heads this movement.

A summary of the subjects discussed by members of the Joliet Astronomical Society, in addition to current topics, follows:

"A Ringside Seat in the Cirro-Stratus"	Harlow D. Grose
"Astronomy Without the Sky"	Raymond D. Cooke
"Daylight Observation of Venus"	Everett C. Shaw
"Theories of Glaciation"	Frank L. Fleener
"Observation of the Noon-day Sun"	Ben Hur Wilson
"Hobnobbing With the Third Planet"	Prof. C. R. Smith
"The Glass Giant of Palomar"	reviewed by Miss A. Dombrowska
"The Nature of Variable Stars"	reviewed by Robert L. Price

Joliet Junior College, Joliet, Illinois

The Cleveland Astronomical Society

Seventy-two members of our society attended the annual dinner meeting on Friday, May 2, at Crosby's Restaurant, Carnegie Ave. and East 105th Street. The committee deserve a great deal of credit as the surroundings were ideal for our group and a fine chicken dinner was served. At 8:15 P.M. we adjourned to the Warner Auditorium, Warner and Swasey Observatory, where Dr. Ernest Cherrington of Perkins Observatory spoke to us on "The Planet Mars." He showed many new slides of the red planet, and his lecture was of absorbing interest from beginning to end. He reviewed the life and work of Percival Lowell who contributed so much original work and who inspired so many amateur observers during his lifetime and even to the present day. Slides showed views of Flagstaff and many of the best drawings and photographs ever taken of Mars.

Dr. Cherrington called attention to the favorable position of the planet for

observation next October. This will be an unusually favorable opportunity, so observers are advised to make the most of it.

After the meeting we were conducted by Dr. Nassau and staff through the many rooms of the new observatory. The library is rapidly expanding and the tools are on hand for a complete machine shop capable of any thing that may be required. Future events include a lecture on Thursday, May 29, at 8:30 P.M., by Professor Bart J. Bok of Harvard College Observatory who will speak on "In Between the Stars."

More than $52.00 worth of new books have just been purchased and are on loan to members.

DON H. JOHNSTON, *Recording Secretary*

Euclid Beach Park, Cleveland, Ohio

The Area of Usefulness of Occultation Predictions

By JACOB HERMANN

When the time $T(\lambda_0, \phi_0)$ and also the longitude and latitude coefficients a and b are known for an occultation visible in longitude λ_0, latitude ϕ_0, the time $T(\lambda, \phi)$ of the phenomenon at a neighboring point in longitude λ, latitude ϕ, may be obtained, approximately, from the formula

$$T(\lambda, \phi) = T(\lambda_0, \phi_0) + a(\lambda - \lambda_0) + b(\phi - \phi_0),$$

where $(\lambda - \lambda_0)$ and $(\phi - \phi_0)$ are reckoned in degrees. This is the formula usually employed in finding the times of occultations at points near central stations, for which the published predictions include the longitude and latitude variations of the times in addition to the times and position angles at the stations themselves. The errors of predictions so obtained, which increase rapidly with distance from the central station, are chiefly due to the following three general assumptions implied in the application of the above formula:

1. The observer concerned is on the plane tangent to the earth's surface at the central station and at just such distances west and north of that position as are obtained by multiplying $(\lambda - \lambda_0)$ and $(\phi - \phi_0)$ by the respective lengths of the degrees of longitude and latitude there.

2. In the vicinity under consideration, a point on the bounding surface of the moon's shadow is at a negligible distance from the plane which is tangent to that surface and on which the central station is located at the time of occultation.

3. In the interval during which the occultation passes over the same region, every point of the earth's surface within that region moves in the same direction and at the same rate as the central station moves at the time of occultation.

It is the purpose of this paper to discuss a method by which partial allowance can be made for the errors introduced through assumptions (1) and (2), and by which it is thus possible to reduce the average error of the predictions at any place so as to increase the distance at which they can be used. The error introduced by the first part of assumption (1) cannot be allowed for without more data than are ordinarily given with the predictions. That caused by the second part of assumption (1), however, can be cancelled once for all, without any additional work for each individual occultation. For reducing the error due to assumption (2), the times, position angles, and longitude and latitude coefficients for both immersion and emersion at the central station are required. The method used necessitates the copying of about one-fourth as many quantities as does that ordinarily used in making a separate computation for each position by means of the Besselian elements. It should thus be most useful to those who are too far from the nearest central station to attain the desired degree of accuracy by apply-

ing the formula discussed at the beginning of this paper, but who are yet sufficiently near it to attain such accuracy by applying the corrections to be derived below.

First let us determine the distances which the observatory in question is west and north of the central station, these distances being measured in the directions of the lines drawn through the central station and tangent, respectively, to its parallel of latitude and meridian of longitude. For this purpose, consider first a system of coördinates in which the origin is at the earth's center; the X-axis is perpendicular to the plane of the central station's meridian of longitude, and is directed eastward as seen from the central station; the Y-axis is coincident with the earth's axis, and is directed northward; the Z-axis is perpendicular to both of these, and is directed so that the Z-coördinate of the central station is positive; and the unit of distance is the earth's equatorial radius. Then the coördinates (X, Y, Z) of any point on the earth's surface whose longitude λ and whose geocentric coördinates $\rho \sin \phi'$ and $\rho \cos \phi'$ are known may be found from the formulas

$$X = \rho \cos \phi' \sin (\lambda_0 - \lambda), \quad Y = \rho \sin \phi', \quad Z = \rho \cos \phi' \cos (\lambda_0 - \lambda).$$

Now set up a new system of coördinates with the same unit of distance, but in which the origin is at the central station; the x-axis is tangent to the central station's parallel of latitude, and is directed eastward; and the y-axis is tangent to the central station's meridian of longitude, and is directed northward. In both systems let the subscripts o and p be used to designate quantities pertaining to the central station and the position of the observer, respectively. Then the required distances west and north are

$$-x_p = -X_p,$$
$$y_p = (Y_p - Y_o) \sec \phi_o + (Z_o - \{Y_p - Y_o\} \tan \phi_o - Z_p) \sin \phi_o.$$

The respective values of these distances in degrees of longitude and latitude as measured at the central station are

$$K_a = Rx_p/L_1(\phi_0),$$
$$K_b = Ry_p/L_2(\phi_0),$$

where R is the earth's equatorial radius, $L_1(\phi_0)$ is the length of a degree of longitude at the central station's latitude, and $L_2(\phi_0)$ is the length of a degree of latitude at the same latitude. Formulas for computing these last two quantities are given in the *American Ephemeris* in the section "Astronomical Constants." The sum of the first order terms to be added to the time of an occultation at the central station to obtain the approximate time of the phenomenon at the neighboring station—neglecting its distance from the plane through the central station tangent to the earth's surface—is thus found to be

$$\Delta_1 T = aK_a + bK_b.$$

Now we shall derive an approximate formula for the sum of those higher-order terms which must be applied to correct for assumption (2). Define w and W by the equations

$$w \sin W = X_p - X_o = X_p,$$
$$w \cos W = Y_p - Y_o.$$

Let $2V$ be the angular distance through which a point passes in moving along the moon's limb from the point of emersion at the central station to that of immersion in the direction in which the position angles are measured. If the north point of the moon's limb is reached during or at the end of the motion referred to, as is usually the case, it is necessary first to increase the position angle at immersion by

360° before subtracting that at emersion to find $2V$. In the following discussion the functions V, P (position angle), and T (time of contact) will be given in the forms F and $F + \Delta F$ for the central station and the neighboring station, respectively; and the subscripts i and e will be used to designate quantities pertaining to immersion and emersion, respectively.

To begin, assume that the central station and the neighboring station move at the same constant rate in the same direction throughout the period of time required to include both of the individual periods which are implicity taken into consideration when the times of both phases of the occultation in question are computed for the latter station from the corresponding times and their first- and higher-order derivatives with respect to longitude and latitude at the former. Assume, furthermore, that the orthogonal projections of the two upon the fundamental plane have the same positions relative to each other as would be the case if the star's declination, and also its hour angle at the central station were both zero. Now imagine, for immersion and emersion separately, a plane fixed to the moon's shadow and tangent to it at the point of contact of the central station. Then, in terms of the earth's equatorial radius,

$$d(P_e, V) = w \cos (P_e + V - W) \csc V$$

is the perpendicular distance from the element of the moon's shadow which lies in that plane to that point of the plane through which the neighboring station passes, this distance being taken positive in the northerly direction of the perpendicular. In terms of the moon's radius, this distance is

$$[d(P_e, V)]/k = (w/k) \cos (P_e + V - W) \csc V,$$

where k is the quotient of the moon's radius divided by the earth's equatorial radius.

Another approximate formula for this distance can be derived on the basis of the first of the above assumptions alone. Compute that part of the change in duration of occultation from the central station to the neighboring station which is due to first-order terms alone with respect to the distances of the latter west and north of the former. This is

$$\Delta_1 D = \Delta_1 T_e - \Delta_1 T_i.$$

In terms of the earth's equatorial radius, the distance at any particular time between the orthogonal projections upon the fundamental plane of the points of the moon's shadow at which the immersion and emersion of the central station occur is

$$l = 2k \sin V.$$

Therefore the approximate rate at which the corresponding projection of the central station passes over this distance relative to the moon's shadow during the duration D is

$$l' = (2k \sin V)/D.$$

But, on the basis of the first of the assumptions above, the change in that distance involved through first-order terms in passing to the foot of the perpendicular dropped from the neighboring station to the plane through the central station tangent to the earth's surface is given, very nearly, by

$$\Delta_1 l = \Delta_1 D l' = (2\Delta_1 D/D)\ k \sin V.$$

From this we find another approximate formula for the required distance, viz.,

$$[d(\Delta_1 D, D, V)/k] = -(1/2k)\ \Delta_1 l \sec V = -(\Delta_1 D/D) \tan V.$$

Because of the errors involved, the values of this distance obtained by the

two methods just developed will generally differ somewhat. In particular, note that the latter is very inaccurate when V is near 90° because an error due to the assumption of uniform motion will then produce a very large error in $d(\Delta_1 D, D, V)$ through the multiplication by tan V, which increases numerically without limit as $V \to 90°$ from either direction. On this account, let us set up a system of weights which will make the limit of $d(\Delta_1 D, D, V)$ times its weight be zero as $V \to 90°$, but which will give a duly increasing weight to this value of d as $|V - 90°|$ increases. We may achieve these ends very simply by giving the weights $\sin^2 V$ and $\cos^2 V$ to the values of this distance obtained by the first and second method, respectively. Then we have

$$(d/k) = (w/k) \cos (P_0 + V - W) \sin V - (\Delta_1 D/D) \sin V \cos V.$$

Now the value $V + \Delta V$ of the function V at the neighboring station may be found approximately from

$$\cos (V + \Delta V) = \cos V + (d/k) \sin V.$$

Within the limits of error of the computations, fulfillment of the conditions $|\cos V + (d/k) \sin V| > 1$ in any particular case, indicates that the star is not to be occulted at the neighboring station.

The absolute value of the distance traveled by the neighboring station relative to the moon's shadow and parallel to the fundamental plane during the time involved by the higher-order terms, which it is necessary to apply to correct for the second assumption referred to at the beginning of this paper, is, in terms of the moon's radius, approximately

$$\sigma = \sin V - (d/k) \cos V - \sin (V + \Delta V).$$

Dividing this by the rate l' and multiplying by the moon's radius k, both with the earth's equatorial radius as the unit of distance, we find that the sum of those higher-order corrections to the initial time T is approximately

$$\Delta T - \Delta_1 T = \pm \sigma D/2 \sin V,$$

where the sign is to be taken positive for an immersion and negative for an emersion.

The approximate correction to be applied to the position angle at the central station to obtain that at the neighboring station is simply

$$\Delta P = \pm \Delta V,$$

where the same rule holds with regard to the double sign.

As an example, let us compute the times and position angles for the occultation of 247 *B*. Tauri at Washington, D. C., on September 25, 1937, from the data published for the station in longitude $+72°\ 30'$, latitude $+42°\ 30'$. In this case the constants pertaining to the relative positions of the two stations are found from the appropriate formulas to be as follows:

K_a	K_b	w/k	W
$+4^s.81$	$-3^s.48$	0.286	232°.7

The following data are given in the *American Ephemeris* for this occultation as visible at the central station used here:

T_1(G.C.T.)	a_1	b_1	P_1	T_0(G.C.T.)	a_0	b_0	P_0
$9^h\ 53^m.3$	$-1^m.9$	$+1^m.4$	51°	$10^h 55^m.4$	$-1^m.4$	$-2^m.4$	304°

It is most convenient to have the work arranged as indicated below, so as to avoid recopying any figures unnecessarily. The best order in which to perform the necessary operations is as follows:

1. Copy T and P from the publication used.

2. Use a slide rule to find the products aK_a and bK_b for both immersion and emersion.

3. Add them separately for each phase to find $\Delta_1 T$.

4. Compute and copy the rest of the quantities in the order in which they appear, except for copying cos V and sin V immediately after having found the duration D.

The necessity of retaining only a limited number of significant figures in the actual computations sometimes results in apparent fulfillment of the impossible relation $\sigma < 0$. In such cases take $\Delta T - \Delta_1 T = 0^m0$.

The complete copy of the required computations is as follows:

P_i	411°		$(w/k)\cos(P_e + V - W)\sin V$	− 0.131
P_e	304		$-(\Delta_1 D/D)\sin V \cos V$	− 0.121
$2V$	107		d/k	− 0.252
P_e	304°0		cos V	+ 0.595
V	53 5		$+(d/k)\sin V$	− 0.203
$-W$	−232 7		cos $(V + \Delta V)$	+ 0.392
$P_e + V - W$	124 8		$V + \Delta V$	66°9
$\Delta_1 T_e$	+ 1^{m}7		V	53 5
$\Delta_1 T_i$	− 14 0		ΔV	+13 4
$\Delta_1 D$	+ 15 7		sin V	0.804
T_e	10^{h}55 4		$-(d/k)\cos V$	+ 0.150
T_i	9^{h}53 3		$-\sin(V + \Delta V)$	− 0.920
D	1^h 2 1		σ	+ 0.034
		Immersion		Emersion
aK_a		− 9^{m}1		− 6^{m}7
bK_b		− 4 9		+ 8 4
$\Delta_1 T$		−14 0		+ 1 7
$\Delta T - \Delta_1 T$		+ 1 3		− 1 3
T		9^{h}53 3		10^{h}55 4
$T + \Delta T$		9^{h}40 6		10^{h}55 8
P		51°		304°
ΔP		+13		− 13
$P + \Delta P$		64		291

I have tested this method by using it to find the times and position angles of occultations of stars as bright as magnitude 6.5 visible at Washington during the year 1937 from the predictions given in the *American Ephemeris* for the station in longitude + 72° 30′, latitude + 42° 30′ and then comparing them with the predictions given for Washington. The average numerical error of the times obtained by the formula given at the beginning of this paper was found to be 1^{m}22; and that of the uncorrected position angles was 9°9. Upon application of the corrections derived above, these were reduced to 0^{m}58 and 2°4, or to 48% and 24% of their original values, respectively. At the same time, the number of errors in time above 2^{m}0 for all the 152 phenomena in question (both phases of 76 occultations) was reduced from 23 to 4; and the number of deviations in position angle greater than 5° was reduced from 105 to 13. No definite conclusions, however, can be drawn from these results as to the relative accuracies of the two methods at other points, since the average error in each case varies in a rather irregular manner with the direction and distance of the neighboring station from the central station, and also with the central station's latitude. Probably one of the greatest disadvantages of the method generally used is that it usually makes the observer expect the emersion too late.

The average value of the distance d depends upon the moon's declination and upon its direction of motion. Therefore the distribution in right ascension of the

occultations used in testing either method should be about the same as that which actually holds for all such phenomena visible at the given station. It is sufficiently accurate to take such occultations scattered through a whole year as have the day of the month for immersion at the central station divisible by a certain integer chosen so that the number of occultations used is great enough for this purpose. I chose the year 1937 because the value of the maximum lunar declination for each month was then near the average of that monthly maximum. The times obtained by the method derived above may be used as preliminary values for obtaining more accurate ones by means of the Besselian elements when testing its accuracy at another station.

Route 3, Box 218, Kenosha, Wisconsin.

General Notes

The Rittenhouse Astronomical Society held its regular monthly meeting on Friday, May 9, at Haverford College. Following a dinner in the Commons Room of Founders Hall, the group went to the Physics Lecture Room of Sharpless Hall, where a lecture on "Atoms and Stars" was given by Dr. Richard M. Sutton, Associate Professor of Physics, Haverford College.

Correction,—Instead of the first line on page 283 of the preceding issue, please substitute the line:

Dr. Robert J. Trumpler, Professor of Astronomy in the University of Cali-

Book Reviews

A History of Magic and Experimental Science. Volumes V and VI: The Sixteenth Century, by Lynn Thorndike, Professor of History, Columbia University. (Columbia University Press. Pages: Vol. V: xxii + 695; Vol. VI: xviii + 766. Price $10.00.)

These two volumes cover roughly the period from 1500 to 1630, completing Professor Thorndike's monumental history of magic and experimental science. They contain a wealth of integrated detail and shed most original light upon this era, which, for confusion of forces, interests, and ideas, hardly had its parallel. Professor Thorndike's work shows the extent of the classical reaction against the ideas and institutions of the Middle Ages, of the spread of vernaculars, of literary popularization, of compendiums and epitomes, of gullibility in high places to quacks, charlatans and intellectual vagabonds, and of the lack of scientific specialization. Professor Thorndike shows how the appending of new facts to outworn systems resulted in the increase of confusion rather than enlightenment; how the quest was for the secrets rather than the laws of nature.

The ravages of religious cleavage and nationalist separatism are made clear, and there is much evidence which surprisingly shows that the natural and occult sciences were established as a common meeting ground where religious and political differences could be ignored and temporarily forgotten. The line of demarcation of social approval and disapproval between magicians and witches was sharply drawn. The volumes present new material on the censorship of the press and

the prevalence of political and religious fugitives and intellectual bootleggers and idea-runners. Here also is new information on persecution and intolerance and the degree to which people escaped therefrom, and on the increase of free thinking and differences of opinion.

At the conclusion of the sixth volume Professor Thorndike has most successfully blazed a way through the maze of medieval and Renaissance magic to the very threshold of modern science. The student of the humanities will be greatly aided and pleased to discover the amount of incidental information that these volumes contain as to education, universities, libraries, and rare editions.

Contents: Volume V: 1. Intellectual Conditions and Characteristics of the Sixteenth Century; 2. Leonardo da Vinci: "The Magician of the Renaissance;" 3. Achillini: Aristotelian and Anatomist; 4. Cocles and Chiromancy; 5. Nifo and Demons; 6. Pomponazzi on Incantations; 7. Symphorien Champier; 8. Agrippa and Occult Philosophy; 9. Varied Approaches to Natural Philosophy; 10. Astrology of the Early Century; 11. The Conjunction of 1524; 12. Astrology at Bologna; 13. The Court of Paul III (1543-1549); 14. Astronomy and Astrology at Paris; 15. Astrology Elsewhere; 16. The Aftermath of Regiomontanus; 17. The Circle of Melanchthon; 18. The Copernican Theory; 19. German Medicine; 20. Brasavola and Pharmacy; 21. Poisons, Fascination, and Hydrophobia; 22. Fracastoro (1478-1553); 23. Anatomy from Carpi to Vesalius; 24. Alchemy During the First Half of the Sixteenth entury; 25. Elements and Occult Virtue; 26. Cardan; 27. Three Technologists: Taisnier, Besson, and Palissy; 28. Gratarolo; 29. The Paracelsan Revival; 30. Thomas Erastus; Appendices. Volume VI: 31. Post Copernican Astronomy; 32. The New Stars; 33. Astrology after 1550; 34. The Catholic Reaction: Index. Inquisition and Papal Bulls; 35. Adversaries of Astrology; 36. Medicine after 1550; 37. Libavius and Chemical Controversy; 38. The Sixteenth Century Naturalists; 39. The Lore of Gems; 40. Cesalpino's View of Nature; 41. Efforts Towards a Christian Philosophy of Nature; 42. For and Against Aristotle; 43. Natural Philosphy and Natural Magic; 44. Mystic Philosophy: Words and Numbers; 45. Divination; 46. The Literature of Witchcraft and Magic after Wier; 47. The Sceptic and the Atheist: Francesco Sanchez and Lucilio Vanini; 49. Summary and By-Products; Appendices; Index.

Publications Received.—The publishers of POPULAR ASTRONOMY hereby acknowledge the receipt of the following named publications and express their great appreciation of the courtesy shown on the part of those who have sent them.

Contributions from the Mount Wilson Observatory—

No. 628. "Accidental and Systematic Errors in Spectroscopic Absolute Magnitudes for Dwarf G0-K2 Stars," by Gustaf Strömberg.

No. 629. "Absolute *f*-Values by the Method of Total Absorption," by Robert B. King and Donald C. Stockbarger.

No. 630. "The Photographic Determination of Stellar Parallaxes with the 60- and 100-inch Reflectors" (Seventeenth Series) by Adriaan van Maanen.

No. 631. "Galactic Rotation and Absorption," by Ralph E. Wilson.

No. 632. "The Mean Coefficient of Selective Absorption in the Galaxy," by Joel Stebbins, C. M. Huffer, and A. E. Whitford.

No. 633. "On the Clustering Tendencies Among the Nebulae," by Erik Holmberg.

No. 634. "A Note on the Evolution of Extragalactic Nebulae," by Gunnar Randers.

No. 635. "The Light-Curve of ζ Aurigae," by William H. Christie.